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Perkin Centennial Week

During 1956 the entire chemical world is paying tribute to an inventive genius in the field of science—William Henry Perkin who is credited with the discovery of the first synthetic dye, mauve. Perkin's discovery which resulted in revolutionizing the dye industry was developed by accident in 1856 when he was attempting to synthesize quinine. This discovery also stimulated creative thinking in a new field which has resulted in the development of countless chemicals and intermediates that are today widely used in industry.

The Centennial of Perkin's discovery will be climaxed by a celebration during the week of September 10 at the Waldorf-Astoria Hotel, New York City. The Centennial is sponsored by 29 organizations including departments of the Government, trade associations, and scientific societies each of which is concerned in some way with the results of Perkin's far-reaching discovery. Each organization is arranging a program on a pertinent topic which is of particular interest to its members. Most of the programs will be talks or symposia. Textile Research Institute, for its part, is organizing a symposium on The Theory of Dyeing. The arrangements for this symposium are by Dr. Howard J. White, Jr., Associate Director of Research, T. R. I.

In addition to the formal meetings, extensive educational features of general interest are being planned. These will include exhibits which furnish the historical background of man's attempts to color materials, illustrate modern uses of colors in industry, fashion, and the home, and depict industries which have grown out of the dye industry.

For further information, write to George O. Linberg, Chairman of the General Program Committee, whose address is Synthron, Inc., 19 Kirkstall Road, Newtonville 60, Mass.

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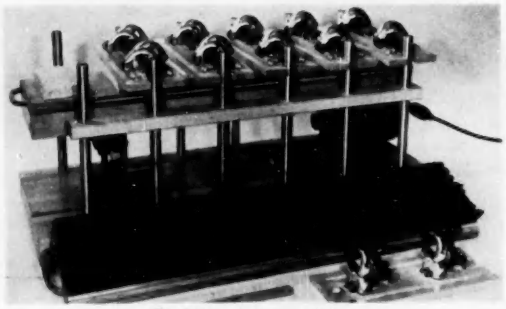

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TEXTILE RESEARCH JOURNAL

VOL. XXVI, NO. 5 MAY 1956

The Arrangement of Fibers in Single Yarns[1]

W. E. Morton[2]

College of Technology, Manchester, England

IN theoretical studies of yarn structure it has hitherto been the usual practice to consider a single yarn as consisting of a core fiber surrounded by coaxial cylindrical layers of other fibers, each forming a perfect helix of constant radius.

Such a structure could not exist as a usable yarn. Not only would it be incapable of withstanding surface abrasion, but also it would be virtually impossible to start developing in the fibers the hoop tensions by means of which they are made to press upon one another and so produce frictional cohesion.

This was recognized by Peirce [2] who accounted for the coherence, which we know yarns to possess, by supposing that the "fibers appearing on the surface have their ends tucked inside." He then went on to say that "an effective geometry of yarn structure awaits the 'theory of random tangle' which has not yet been developed." However, consideration of what happens to fibers, while they are in the process of yarn formation immediately in front of the rollers of the spinning frame, suggests that while there must be tangle, it is not necessarily random.

Fiber Migration

The highly idealized form of structure mentioned above would not only be useless if it existed; it could not even be made, at any rate by any of the known methods of spinning. Recognizing that the paths followed by the fibers in a yarn vary in length according to their distance from the yarn axis, it is evident that to produce such a structure, each fiber would have to be delivered for twisting at a rate appropriate to the position it is destined to occupy in the yarn. This is of course impracticable. All the fibers are delivered at the same rate. It follows therefore that since the length of the fiber path increases from the core to the surface, so also must the tension in the fibers. At any given instant, those forming the outer layer of the yarn follow the longest path and are consequently highly stressed; furthermore, the curvature of their path is also the largest. The resultant force acting towards the core, or yarn axis, is therefore a maximum for these fibers. The corresponding forces exerted by those in the inner layers is smaller, decreasing towards the core where it is zero.

As a result of these radial forces, those parts of the fibers emerging from the front rollers of the spinning frame, which are yet to reach the point of actual yarn formation, are all, in varying degree, competing to occupy the axial position. Those momentarily forming the surface layers will therefore tend to move in toward the core position, displacing the less highly tensioned fibers already there, and in due course are themselves displaced when their tension has fallen. The expectation, therefore, is that in tracing the positions occupied by a fiber in a yarn point by point along its length, it will be seen to

[1] Presented at a meeting of The Fiber Society, Cambridge, Mass., September 8, 1955. Also presented in part at the International Congress of Scientific and Applied Research, Brussels, Belgium, June 27, 1955. Published in the Proceedings of the Annales Scientifiques Textiles Belges in March 1956.

[2] Professor of Textile Technology.

traverse back and forth across the imaginary cylindrical zones of the structure, in parts being at or near the surface and in parts at or near the core. This interchange of zonal position, of course, provides the necessary tangle.

That behavior of this kind is observed in practice, was shown by Morton and Yen [1], using a tracer fiber technique of investigation, and the term "fiber migration" was used to describe it. The path of a fiber in a yarn is in fact a helix of which the radius is alternately increasing and decreasing along its length. In one complete migration cycle it is very rarely that a fiber traverses through all zones of the structure, from the surface to the core and back again: such perfect behavior is perhaps not ordinarily to be expected in any textile material. Nor are the intervals between successive reversals anything but variable. Nevertheless observed behavior is at least in keeping with theoretical expectation.

As for fiber ends, it is obvious that as soon as a trailing end emerges from the nip of the front rollers, the tension in the fiber must drop to zero. It is then in no condition to do other than suffer expulsion to the surface, where it will appear as projecting fiber. This is in fact where nearly all trailing fiber ends are found, not tucked in, as postulated by Peirce.

The Tracer Fiber Technique

The tracer fiber technique itself, and suitable methods of characterizing the migratory behavior observed, have already been described in some detail elsewhere [1, 3], but may be briefly summarized as follows.

To the raw stock from which the yarn is spun, a small quantity (about 0.1%) of colored fiber is added to act as tracers, it being assumed that in every material respect these behave in the same way as the uncolored fibers. When the yarn is immersed in a liquid of suitable refractive index, the uncolored fibers almost disappear from view when the yarn is examined under a microscope, and the path of each tracer can be clearly discerned. The tracer is seen against the faint background of the body of the yarn as a wavy line representing the projection in one plane of a helix, each wave corresponding to one turn or twist. By means of a micrometer eyepiece the location of the tracer with respect to the upper and lower yarn boundaries can be observed at the peaks and troughs of successive waves, the intervals between which are noted on the vernier scale of the traversing stage. In this way all the necessary data is obtained for plotting on a large sheet of squared paper, and to suitable scale, the expanding and contracting helix radius throughout the length of each tracer examined. It is useful to think of such a plot as the projection in one plane, and on one side of the yarn axis, of the envelope which just encloses the fiber throughout its length. Examples are shown in Figures 1 and 2.

In characterizing the features of the helix envelope, it is convenient to imagine the yarn as divided up into five concentric zones, or cylindrical layers, of equal thickness. Thus in Figure 2, the horizontal lines represent the yarn axis and the outer boundaries of the five zones. What is required is some means of describing fully the manner in which the tracer traverses back and forth across these boundaries from one end to the other.

Frequency of Reversal

Perhaps the most obvious point of interest in the migratory behavior of a fiber is the frequency with which reversals in the direction of migration take place. In the fiber to which Figure 2*a* relates, migration is nowhere complete, yet it is clear that four cycles of partial migration have taken place in the 28-mm. yarn length concerned. We could therefore say that the frequency of reversal for this fiber is characterized by a mean migration period of 7 mm., and from a large number of such fibers a mean migration period for the yarn as a whole could be obtained.

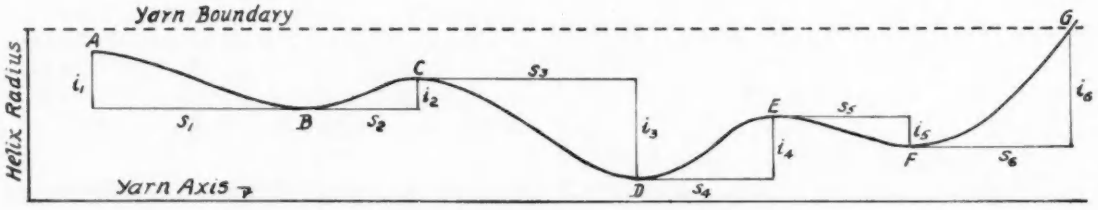

Fig. 1. Fiber migration shown by changing radius of helix envelope.

In practice, difficulties are encountered: first, because it is not always easy to decide whether a small reversal in direction of migration is a real one and not merely the result of a slight kink in the fiber occurring at the point of observation; and second, because there is evidence to show that the axis of rotation of the helix is not always where it is assumed to be in the graphical analysis, namely midway between the upper and lower yarn boundaries. As already explained elsewhere [3], this can lead to the appearance of changes in envelope radius which are obviously spurious. The mean migration period is nevertheless considered to be the most satisfactory quantity by which to characterize the rate of reversal, and methods of overcoming the difficulties mentioned are being investigated.

An alternative method is to record the number of times per unit length of yarn that the helix envelope cuts through all of the zone boundaries. The total number of cuts for each tracer is counted, divided by the tracer extent, and averaged for all the tracers examined. The results obtained, however, depend not only on the frequency of reversal, but also on the completeness of the migration. Thus two fibers might have the same number of reversals in a given length, but if one migrates fully between core and surface while the other migrates back and forth between only, say, two zones, the former will show a larger number of cuts.

On the other hand, in studying yarn structure we are concerned with the behavior of a considerable number of fibers in combination, and if, over a sufficiently large sample of fibers, two yarns are seen to have substantially the same pattern of migration, then the "cuts-per-unit length" method would seem to be valid, at least for comparative purposes.

In the early stages of the work, this method was used in one limited set of experiments to ascertain how yarn twist affects the rate of migration reversal. The results are of interest and are summarized in the following table.

Total Cuts in 28 mm. of Yarn Length
Yarn ring-spun from $1\frac{7}{16}$-in., 1.5-den. Fibro

Yarn count (cotton system)	Twist factor		
	2.0	3.5	6.0
9's	24	31	76
50's	41	63	113

Although only ten tracers in each yarn were examined, the results show fairly conclusively that the frequency with which fibers reverse their direction of migration is influenced both by the count and by the amount of twist inserted.

The effect of twist is of particular interest because it constitutes evidence that the tangle is not altogether random. If the tangle were random and arose simply from random criss-crossing of the fibers as they emerge from the front rollers, one would expect the whole pattern of migration, including the frequency of reversals, to be independent of the amount of twist inserted. But this is not so. The interval between reversals obviously decreased as twist increased in both counts of yarn.

And this, of course, is precisely what one would expect if our explanation of the origins of migration is correct. It is held that migration *must* take place because of the differences in tension generated among the fibers, according to the positions they occupy at the point of yarn formation. The greater the amount of twist inserted, the shorter the length of yarn that must be spun to develop the necessary tension differences, and consequently, the greater the frequency of reversals.

As for the differences between the 9's and the 50's, one possible explanation, at least, is that the greater the number of fibers in the yarn cross section, the

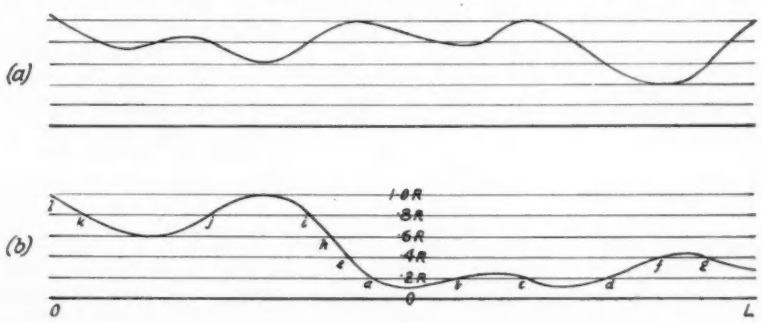

Fig. 2. Examples of helix envelope showing arbitrary zone boundaries.

greater the obstruction which each fiber has to overcome in migrating through a given fraction of the yarn radius. In other words, greater tension differences must be developed among the fibers in the coarse yarn in order to produce the same effect.

Coefficient of Migration

As has been stated, very few tracers among the many hundreds we have so far examined have displayed complete migration in any one cycle. In one period, a fiber may traverse across only one or two zone boundaries, while in another it may traverse across three or four, or even all of them. The completeness, or otherwise, of a given migratory traverse may be evaluated by the change in helix radius between successive inflexions of the helix envelope, expressed as a fraction of the yarn radius. Thus in Figure 1, the intensity of the migration from A to B is $(r_A - r_B)/R = i/R$. But in addition, we require some means of evaluating the completeness or otherwise of the migration displayed by the fiber as a whole. For this, a quantity which may be called the coefficient of migration is used. Again referring to Figure 1, where in each migration the fiber traverses through a radial distance i over a yarn length s, the coefficient of migration is given by

$$C = \frac{i_1}{R} \times \frac{s_1}{L} + \frac{i_2}{R} \times \frac{s_2}{L} + \frac{i_3}{R} \times \frac{s_3}{L} + \cdots = \frac{\Sigma is}{RL}$$

where L is the yarn length. If migration is perfectly complete throughout the extent of the tracer, $C = 1$, while if no migration takes place, $C = 0$.

Thus the coefficient of migration, as defined, is a dimensionless quantity which may lie anywhere between zero and unity. As an example of the kind of figures one obtains, and of the variation to be found from fiber to fiber, the results for a 12's Fibro yarn, spun from double roving with a twist factor of 3.5, may be quoted. For this yarn, the coefficient ranged from 0.09 to 0.56 with a mean for 50 tracers of 0.28 ± 0.014. Very low figures, such as the 0.09 noted here, are characteristic of what we call "wild" fibers, of which more will be said later.

Zonal Distribution

Last we have to recognize that two fibers may have the same coefficient of migration and yet be distributed quite differently in the yarn structure. Thus in Figure 2 are shown the semienvelopes of two fibers, a and b, having $C = 0.259$ and 0.253, respectively. Yet fiber a migrated moderately among the outer zones throughout its length, while fiber b migrated for about one third of its length among the outer zones and then, after an intense traverse inward, almost to the core, continued to migrate very slowly among the inner zones for the rest of its length. It is obviously desirable to have some means of portraying graphically such differences in behavior, and the simplest way of doing this is to construct block diagrams showing the volumetric contribution which each fiber makes to the different zones of the structure.

First, because of the immense labor that would otherwise be involved, we assume the yarn diameter to be constant throughout the length containing the tracer. This is of course not strictly true, though in all but a few of the cases we have so far examined, the error has been small compared with other uncertainties involved in work of this kind. In any case, as is well known, it is not easy to locate with accuracy the boundaries of a yarn when viewed under the microscope. Projecting ends, and more especially, projecting loops of fiber make judgment difficult.

So, from the observations of diameter, the mean yarn radius, R, is calculated, and a straight line is drawn parallel to the "yarn axis" line and separated from it by a distance representing the mean radius to some convenient scale. The intervening space is then divided into five equal parts as shown, representing five zones of radius $0.1R$, $0.3R$, $0.5R$, $0.7R$, and $0.9R$. If it should happen that the tracer appears on the surface at a point where the yarn radius is greater than the mean, then its path lies outside the fifth zone, but it is, of course, counted as lying within that zone.

Fig. 3. Typical zonal distributions for individual fibers.

In Figure 2*b*, the curve *l, k, j, i* . . . represents a helix envelope in a length of yarn, *OL*. The tracer occupies the first zone over a yarn length $ab + cd$, the second zone over a length $ef - (ab + cd)$, and so on for the other zones. Thus the percentage of the yarn length occupied by the tracer in each of the five zones can be calculated. Obviously, the sum of all yarn lengths so occupied over the five zones is equal to the yarn length, *OL*, considered.

To obtain the percentage fiber length P contributing to each zone, a correction must be made for the differences in helix angle among the zones. For this, it is necessary to know R, the yarn radius, and h, the length of one turn of twist. R is observed directly, and h can nearly always be obtained without any difficulty by counting the number of waves in the original fiber projection, assuming that the rate of twist does not vary much over the length concerned. Then the correction factor to be applied is $l/h = \sec \tan^{-1} (2\pi r/h)$ where r is the zone radius, $0.1R$, $0.3R$, etc., as the case may be.

By plotting P against r a block diagram can be prepared showing the zonal distribution of each fiber. Figure 3 shows some of the different types of zonal distribution diagrams that can be obtained. Diagrams similar to (*b*) are much the commonest.

Type (*d*) is encountered occasionally and refers to one of the "wild" fibers that have already been mentioned. Over the greater part of its length it has been simply lapping around the outside of the yarn, and in many such cases it has been noted that the fiber lies loosely on the surface, at times tending to loop away from it altogether. The explanation for their occurrence is evidently that such fibers never start to be bound into the structure; their leading ends are insecurely anchored, or not anchored at all, so that they can readily accommodate themselves to the long path they have to follow, simply by slipping. They are unable to develop sufficient tension to start migrating, and perhaps barely avoid being thrown off into the air as fly.

Mean Zonal Distributions

If the specific volume, i.e., the density of fiber packing is uniform over the yarn section, then evidently the total length of fiber in each zone is proportional to the volume of each zone, and so increases linearly with zone radius. Therefore, for a sufficiently numerous and representative sample of fibers, the mean block diagram should show linear increases in the height of the columns from zone 1 to zone 5, as shown by the dotted line in Figure 4. In fact, however, all but one of the yarns we have so far examined (viscose or acetate staple fiber in various counts and twists) have shown mean zonal distributions like that shown by the full line, indicating that the specific volume increased quite sharply near the surface. It is probable that this not altogether unexpected feature is characteristic of most yarns.

Effect of Fiber Position as Delivered by the Front Rollers

Even though we might accept the proposition that the pattern of fiber migration has its origins in the tension differences, as already explained, it still remains possible that it might be influenced by other factors as well. Two possibilities present themselves. One is that the migratory behavior of a fiber might differ according to whether it emerges through the front rollers in the middle, or, alternatively, towards one or another of the fringes of the ribbon of drafted roving. The other possibility arises from the fact that the two fringes of the emerging ribbon of fibers are not treated alike. In a *Z* twisted yarn, for example, fibers in the r.h. fringe of the ribbon are free to fold *over* toward the left at the point of yarn formation; whereas, because of obstruction by the top breast of the bottom roller, fibers in the l.h. fringe are not similarly free to fold *under* toward the right. To investigate this, two lots of 12's yarn were spun from 1 7/16-in., 1.5-den., bright Fibro with a twist factor of 3.5 in the *Z* direction. Double roving was used but tracer fibers were incorporated in only one, which for convenience we shall call the tracer roving.

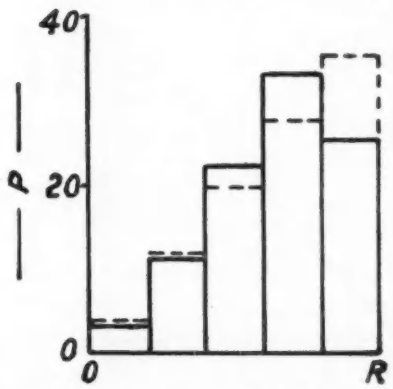

Fig. 4. Mean zonal distributions.

In one lot of yarn, identified by the symbols $2/L/Z$, the tracer roving was fed on the l.h. side, and in the other, identified by the symbols $2/R/Z$, on the r.h. side. Fifty tracers were then examined in each lot of yarn, and the results compared. No significant difference was found in the frequency of reversals, or coefficient of migration, or in the zonal distribution of the tracers, though in the latter there was a suspicion that the tracers fed at the l.h. side tended to be slightly more concentrated in the outer zone. The zonal distributions in the form of curves are shown for the two yarns in Figure 5.

It was then realized that the experiment was not likely to lead to any sharp discrimination, because quite a large number of tracers were likely to lie near the middle of the emerging ribbon of fibers, whichever of the two rovings they were in. It was therefore decided to spin with the same materials, count and twist, a second series of three yarns spun from triple roving, the tracer roving occupying the l.h., middle, and r.h. positions respectively. These yarns are identified by the symbols $3/L/Z$, $3/M/Z$, and $3/R/Z$.

Again, no significant difference was found in rate of reversal, but this time the tracers did not behave alike either as regards the coefficient of migration or as regards the zonal distribution. The mean values of C were as follows:

$3/L/Z$	0.211
$3/M/Z$	0.294
$3/R/Z$	0.240

The difference between the $3/L/Z$ and $3/R/Z$ results was not significant, but the $3/M/Z$ result was significantly greater than either of the other two.

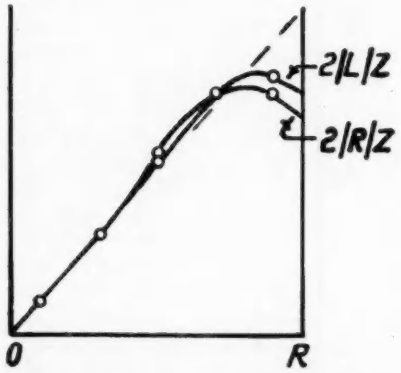

Fig. 5. Zonal distribution curves for double roving yarns.

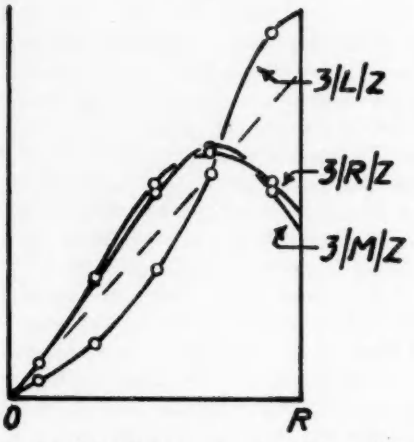

Fig. 6. Zonal distribution curves for triple roving yarns.

The zonal distribution curves are shown in Figure 6. Here it is seen that there was little difference between the $3/R/Z$ and $3/M/Z$ tracers, but that the $3/L/Z$ tracers were contributing far more than their fair share to the outer zones. An examination of the data for individual fibers disclosed that this was primarily, if not entirely, due to the occurrence of wild fibers. In the $3/L/Z$ yarn there were 11 such fibers out of 50, in the $3/R/Z$ yarn there were 2, and in the $3/M/Z$ yarn, none. Obviously, a substantial proportion of the l.h. fringe fibers were difficult to incorporate in the yarn at all, which is perhaps what one would expect; and the only reason the r.h. fringe fibers did not behave in a similar way was because they could fold over into the cone of fibers at the point of yarn formation.

We may now refer back to the results for the double roving yarns, and note that there also, the l.h. tracers tended to be more concentrated in the outer zones. A larger number of tests might well have shown this difference to be real.

A practical outcome of all this is that in the spinning of mock grandrelle yarns, it might be a matter of some importance to control the positions in which the two differently colored rovings are passed through the drafting rollers. Otherwise, noticeable differences in shade might arise, sufficient to produce faults in fabrics.

A further practical outcome is that since wild, or "wildish" fibers, (we must recognize that there are degrees of wildness) are unlikely to contribute their fair share to the strength of the yarn, the width of

the ribbon of drawn-out roving should be limited as much as possible.

Behavior of Fiber Blends

If, as we have postulated, the migratory behavior of fibers in yarns arises from differences in tension developed during the process of yarn formation, then it is to be expected that in a blended yarn, composed of two types of fibers differing in their initial Young's modulus, those having the higher modulus would tend to occupy preferentially the inner zones of the structure, and those having the lower modulus, the outer zones.

Experiments have been carried out to test this hypothesis by observations on a blend of viscose and acetate staple, and though some positive evidence has been obtained, it is not altogether conclusive and further work will have to be done. However, F. Charnley of the British Rayon Research Association has demonstrated that in a 50–50 blend of viscose and acetate, both 3-den. and of 2 ½-in. staple, the latter, having the lower modulus, does tend to occupy preferentially the outer zones. This was done by making two fabrics, one containing 50% by weight of black acetate blended with white viscose, and the other containing 50% of white acetate blended with black viscose. The two fabrics differed very markedly in shade, the former being much the darker. It might be argued that this was simply due to the fact that 50% by weight of acetate would be about 54% by volume, because of its lower density, though it is extremely doubtful whether this would be sufficient to account for the marked difference in shade that was found. But abrasion of the surfaces of the two fabrics showed indisputably that the difference was in fact due to a difference in fiber arrangement; the dark fabric became lighter in shade where worn, and the light fabric darker.

From the point of view of yarn strength, it is unfortunately a disadvantage if the less extensible components of a blend tend to concentrate in the inner zones because when the yarn is under tension, the maldistribution of stress over the yarn section is thereby accentuated.

Blends of Different Fiber Lengths

As we have seen, theory indicates that practically all trailing fiber ends should appear on the outside of the yarn. If therefore a blended yarn is made, consisting of two different lengths of fiber in equal proportions by weight, the shorter component should be more evident on the surface, because, of course, it has more ends per unit volume. For evidence in support of this, I am indebted to Dr. P. P. Townend of Leeds University. Two lots of yarn were cap-spun from blends of 50% black and 50% white Fibro.[3] In both, the white component was 6 in. in length, but whereas in one the black component was also 6 in. in length, in the other it was only 4 in. When made up into knitted fabric, the latter was noticeably darker in shade.

The Effects of Two-Stage Twisting

Once a yarn has been made, the pattern of fiber migration appropriate to the conditions of spinning is fixed; except perhaps in the milling of a wool yarn, no point on a fiber can thereafter be translated from one zone of the structure to another. But if further twist is added, the yarn contracts in the process and this, it would seem, must lead to a buckling of those parts of the fibers lying near the core. If this happens, then the distribution of stress among the fibers in a tensile test must be quite different from that in a yarn spun with the same amount of twist in a single operation. Differences in yarn strength must ensue, and we have already demonstrated that this is so; within certain limits of final twist, double-spun yarns are stronger than single-spun. Whether or not this is due to buckling at the core in two-stage twisting is not easy to prove, but work along these lines is proceeding. Part of the difficulty arises from the possibility that kinking of a fiber may be easily confused with crimp.

In conclusion, it may be of interest to note that all mule spinning involves two-stage twisting in one degree or another, especially when twisting at the head is employed. This could be the cause of a fundamental difference in structure between ring- and mule-spun yarns.

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[3] Registered trade name of viscose staple fiber produced by Courtaulds Ltd., England.

The Estimation of Sulfhydryl Groups in Wool by Means of 1-(4-Chloromercuriphenylazo)-Naphthol-2

Part I: Experiments on Intact Fibers

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IT has recently been reported [4] that sulfhydryl groups in wool fibers may be detected and estimated by means of a formamide solution of Bennett's color reagent, 1-(4-chloromercuriphenylazo)-naphthol-2 [1, 15, 16]. Further experiments have now shown that the acidity and water content of the formamide are important in determining the rate and extent of penetration of this reagent into the fiber, and that the values reported earlier are therefore too low. This communication gives directions for increasing the reliability of the method for use on intact fibers and describes the standardization of the reagent on known sulfhydryl compounds. A subsequent communication will describe how the method can be shortened by using supercontracted and pulverized wool. A brief outline of the methods, without experimental details, has already been given [5].

Materials

Wool

The wool samples used, which unless otherwise stated, were from the root ends of one good quality South African merino fleece (from sheep *B*51.3), were purified by Soxhlet-extraction for 24 hr. with hexane, then for 12 hr. with ethyl alcohol, followed by soaking for 24 hr. in frequently changed distilled water.

1-(4-Chloromercuriphenylazo)-Naphthol-2

This was prepared by the method of Bennett and Yphantis [2].

Formamide

Technical grades were purified by distillation under low pressure (0.1 mm., b.p. 55° C.). If the formamide contained much water, up to half the distillate had to be discarded before a sufficiently pure fraction was collected. The acidity of the distillate was estimated by measuring the pH of a small quantity after dilution with five times its volume of water. A typical distillate had a pH of 4.5 as defined in this way, and was 0.005 *N* with respect to acid, presumably formic acid. This acid was neutralized with solid anhydrous sodium carbonate until the pH after dilution was between 7.8 and 8.2.

The anhydrous formamide required for the preparation of solutions with known water contents (Figure 1) was obtained by crystallizing a redistilled sample [13].

β-lactoglobulin

Bovin β-lactoglobulin, lot *A*4801, from Pentex Inc., Illinois, was used.

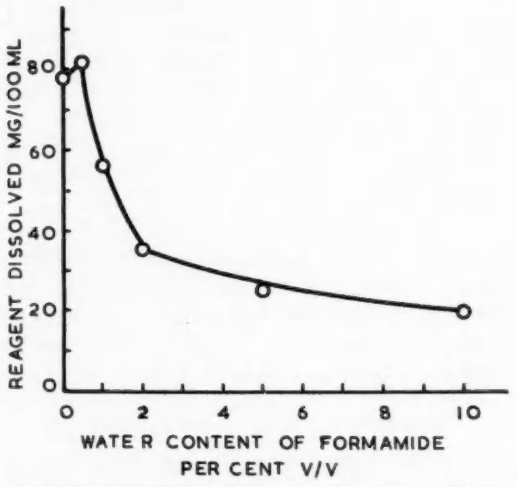

Fig. 1. The relation between the solubility at 30° C. of the color reagent in formamide (pH 7.0) and the water content of the formamide.

Methods

Formamide Solutions of the Color Reagent

These were prepared by dissolving a known quantity of the reagent (2 to 3 mg.) in formamide (100 ml.) that had been freshly distilled and neutralized as described above.

A curve giving concentration of reagent against optical density was plotted, and Beer's law was found to be obeyed up to a concentration of about 3 mg./100 ml. The optical density was independent of pH from 4 to 9.5 at least, and of water content from 0 to about 10%.

For all colorimetric measurements a "Spekker" absorptiometer was used with blue-green no. 603 filters and 1-cm. absorption cells. Distilled water was used as blank.

The Estimation of Sulfhydryl Groups in Intact Wool Fibers

For a normal wool containing about 20 micromoles of sulfhydryl groups per gram, six samples of between 10 and 15 mg. were weighed out. The moisture content was determined on another sample by heating to constant weight at 105° C.

Each of the six samples was sealed in a glass tube with 10 ml. of a formamide solution of the color reagent and left at 30° C. with occasional shaking—once or twice a day. The tubes were opened at intervals of two or three days, the fibers were filtered off, and the color intensity of the filtrate was measured. For a normal merino wool, about 14 days were required for the colorimetric readings to reach a steady value. About 25 days were required for a sample of mohair.

The sulfhydryl-group concentration of the wool was calculated from the amount of color reagent taken up by the fibers and was expressed as micromoles per gram of dry wool.

Sealed tubes were used to prevent moisture absorption by the formamide. The speed of the reaction could be increased slightly by gentle mechanical shaking of the mixtures; vigorous shaking caused the fibers to felt into a tight ball.

Standardization of the Color Reagent

No well-defined insoluble protein was available on which to check the suitability of formamide solutions of 1-(4-chloromercuriphenylazo)-naphthol-2 for the estimation of sulfhydryl groups. Accordingly a procedure for using soluble sulfhydryl compounds was developed and is described for the case of glutathione.

To 1.0 ml. of a standard, freshly prepared solution of glutathione in formamide (the concentration being about 10 mg./100 ml.), 10.0 ml. of a solution of the color reagent was added. The solution was stoppered and left at room temperature for about 30 min., then 10.0 ml. of freshly distilled dimethylaniline was added. After shaking, the mixture separated into two layers. The lower, formamide layer, containing the colored compound formed by the action of the reagent on glutathione, was discarded, and the upper, dimethylaniline layer, containing the excess reagent, was filtered through a double layer of paper to remove suspended droplets of formamide. The color intensity of the filtrate was then measured and the amount of unreacted reagent obtained from the Beer's law graph for solutions of the reagent in dimethylaniline.

Extraction of the color reagent into dimethyaniline is almost quantitative, although the accuracy could be increased by correcting for the small amount not extracted. This correction was best determined for each batch of formamide by extracting a series of standard solutions with dimethylaniline.

Duplicate results for the sulfhydryl-group concentration in glutathione, using the same batch of formamide, agreed to within 2% and were usually within 5% of the theoretical value. There were, however, differences between the results for different batches of formamide, probably because of variations in water content. Thus a formamide solution of pH 8.2, to which 10% of water had been added, gave a result in error by -12%. It is therefore necessary to use formamide with a low water content; less than 2% is recommended. The water content is not easy to measure, although an indication is given by the amount of reagent that dissolves, as mentioned in the next section.

β-lactoglobulin was also used as a test compound. To a sample of 2 to 3 mg. of β-lactoglobulin of known moisture content, 10.0 ml. of a formamide solution of the color reagent was added. The mixture was stoppered, shaken to dissolve the protein, and left for about an hour at room temperature (21° C.). The procedure was then exactly the same as for the glutathione estimation.

The reaction with β-lactoglobulin was complete in about an hour and no further reaction could be detected if the mixture was left for as long as 7 days.

The average value for 5 estimations on β-lactoglobulin, using different batches of formamide, was 97 micromoles of sulfhydryl groups per gram, with a standard error of 6 micromoles/g. A value of 92 micromoles/g. was found by Brand and Kassel [3]. This indicates that formamide solutions of 1-(4-chloromercuriphenylazo)-naphthol-2 are suitable for the estimation of sulfhydryl groups in proteins.

For estimations on both glutathione and β-lactoglobulin, low results were obtained if the pH of the formamide solution was below about 6.

Experimental

The Solubility of 1-(4-Chloromercuriphenylazo)-Naphthol-2 in Formamide

Difficulty was sometimes experienced in preparing solutions until it was found that the solubility of the color reagent in formamide depends on the water content and the acidity, or some related property. It was found impossible to dissolve the reagent in acidic formamide with a high water content. The relations are shown approximately in Figures 1 and 2, for which the reagent concentrations were determined colorimetrically. As before, the pH refers to the value after dilution with five times the volume of water.

For maximum solubility the formamide should have about 1% of water and a pH of more than 6.

The Penetration of the Reagent into Wool Fibers

Formamide swells intact wool fibers sufficiently to allow the large color-reagent molecules to penetrate [6], although the rate of penetration, and therefore the rate of reaction with sulfhydryl groups, is very slow. As in the case of glutathione and β-lactoglobulin, the acidity of the formamide is important. This is shown in Figure 3 in which curves A, B, and C give the rate of reaction with intact wool fibers of equimolar solutions of the reagent with different acidities; the acidity being expressed, as before, as the pH after dilution with water.

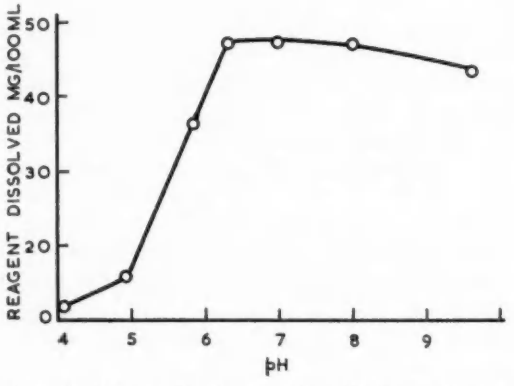

Fig. 2. The relation between the solubility of the color reagent at 30° C. and the pH of the formamide, as defined in text. The solutions each contained 1% of water or an appropriate aqueous buffer.

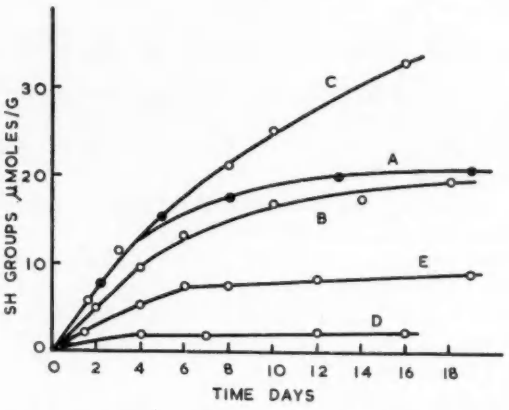

Fig. 3. The rate of penetration of the color reagent in formamide of different pH values into fibers of merino B51.3. Formamide of A, pH 7.9; B, pH 7.0; C, pH 9.1; D, pH 7.9; wool pretreated with mercuric chloride solution, E, pH 7.9; wool pretreated with N-ethylmaleimide solution.

Curve A shows that at pH 7.9 the reaction reached completion in about 14 days, the value taken for the sulfhydryl group concentration of the merino wool sample being 21 micromoles/g. At pH 7.0 (curve B) the rate was slower but the same limiting value was reached. At pH values lower than about 6 the rate was much slower and the same limiting value was not reached even after 60 days. Experiments at low pH values were sometimes complicated by the precipitation of the reagent as red specks on the surface of the fibers.

At pH values higher than about 8.5 the reagent was absorbed continuously, and no limiting value was reached. Curve C, for example, refers to a solution of pH 9.1. It is possible that under these conditions new sulfhydryl groups were formed from disulfide bonds by the alkaline solution. A value of from 7.8 to 8.2 is therefore recommended for the pH of the formamide solution because it allows the most rapid rate of reaction without the formation of new sulfhydryl groups.

Microscopic examination of the fibers during the course of the reaction showed that the color reagent did not penetrate uniformly. With the formamide solution at pH 7.9, reddish patches appeared in the fibers during the first two days which tended to concentrate in one of the bilateral segments [7, 9]. After 4 days the staining was less patchy but in most fibers only one bilateral segment was stained. By 10 days the fibers were uniformly stained and the two segments were almost indistinguishable. With acidic formamide (pH 5.1), differential staining was more noticeable; after 20 days, when 9 micromoles/g. had reacted, one bilateral segment was uniformly stained and the other almost unstained. This was probably a result of the differential swelling of the bilateral segments.

The specificity of the color reagent for sulfhydryl groups in wool was examined by using wool samples pretreated with sulfhydryl blocking agents. Figure 3, curve D, shows that with wool pretreated for 4 days at 30° C. in 0.001 *M* mercuric chloride (wool to liquor ratio 1:1000), there was very little reaction. Tests on wool pretreated for 10 days at 30° C. in a 0.05 *M* solution of N-ethylmaleimide [8] in pH 7.4 phosphate buffer (wool to liquor ratio 1:250) were less satisfactory. Curve E shows that after 14 days 8 micromoles of the reagent had reacted per gram of this wool, which therefore probably contained sulfhydryl groups inaccessible to aqueous N-ethylmaleimide [14].

A more reliable test of the specificity of the reagent, but one that could not be done quantitatively, consisted in treating a sample of wool that had already reacted to completion with 1-(4-chloromercuriphenylazo)-naphthol-2 with a sulfhydryl compound [1]. In practice, the wool sample was shaken at 30° C. for 24 hr. with an excess of cysteine in formamide (pH 7.4). The red color was displaced from the wool which became a very faint pink. The color was not displaced from another wool sample shaken in formamide at a similar pH but without cysteine.

These tests suggest that under the conditions used the reagent reacts with nonsulfhydryl groups in wool fibers to an extent of not more than one or two micromoles/g., which is considered to be within the limits of accuracy of the method.

The results of sulfhydryl-group estimations on three samples of merino wool and one of mohair are given in Table I as an illustration of the application of the method. A sample of merino wool in which extra sulfhydryl groups had been produced by shaking for 1 hr. at 30° C. in 1% sodium bisulfite (wool to liquor ratio 1:250) and then washing in water for 12 hr. is included. In this sample many of the sulfhydryl groups produced by the bisulfite treatment were probably oxidized during washing so that the value is lower than expected. All the wool samples tested so far, excepting those pretreated with certain blocking agents, have been found to contain sulfhydryl groups.

Discussion

From the preceding experiments it is clear that the amount of water and acid in the formamide are very important in determining the solubility of 1-(4-chloromercuriphenylazo)-naphthol-2 and the extent of its reaction with sulfhydryl groups in wool and simpler substances. For the reaction with wool the influence of pH on the swelling of the fibers probably plays a part as well. Within the specified limits of pH and water content, formamide solutions of the reagent may be used for reproducible and extremely sensitive estimations of sulfhydryl groups in intact wool fibers. A few examples of the application of the method are given in Table I, and other results will be reported later.

There have previously been few attempts to estimate sulfhydryl groups in wool. Qualitative colorimetric tests, such as the nitroprusside test [12], have not detected these groups in untreated fibers. From the presence of cysteine in wool hydrolysates, it has been known for many years that a few sulfhydryl groups are present in wool. The difficulties in using this method for quantitative estimations have been discussed by Park and Speakman [11]. Monder and

TABLE I. Sulfhydryl-Group Concentrations in Wool Samples

Wool	SH groups (micromoles/g.)
Merino B51.3	20
	21
	21
Merino Hr1	20
	20
Merino G5	18
Cape Mohair	32
Merino B51.3 (reduced with bisulfite)	42

Ramstad [10] estimated sulfhydryl groups in pulverized wool by the iodosobenzoic-acid method, and Zuber, Trauman, and Zahn [17] have recently estimated them as s-dinitrophenylcysteine after the hydrolysis of dinitrophenylated wool. A direct comparison of these methods is not yet possible because different wool samples have been used.

Acknowledgments

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Part II: Experiments on Supercontracted and Pulverized Fibers

IT was shown in Part I that formamide solutions of 1-(4-chloromercuriphenylazo)-naphthol-2 may be used to estimate small quantities of sulfhydryl groups in wool fibers, provided that the formamide is sufficiently free from acid and water. The method has the advantage that reaction occurs under very mild conditions, but there is the disadvantage that two weeks are required for an estimation on merino wool and longer still for coarse fibers. The limiting factor is the rate of penetration of the reagent into the fibers since reaction with the sulfhydryl groups of the soluble protein, β-lactoglobulin, is very rapid. Two methods for breaking up the structure of the fiber to allow the reagent to penetrate more rapidly have been studied, namely, supercontraction in hot phenol and pulverization. Conditions have been found whereby the results obtained after these processes are the same as those obtained on intact fibers. Earlier experiments [3], which suggested that wool supercontracted in phenol contains more sulfhydryl groups than normal, have been found to be incorrect.

Materials

Most of these were the same as described in Part I. The formamide solution of 1-(4-chloromercuriphenylazo)-naphthol-2 contained from 2 to 3 mg./100 ml. and after diluting a portion with five times the volume of water, the pH was between 7.8 and 8.2.

Phenol

Freshly distilled phenol of good quality was used. It has been shown by Zahn [11] that for supercontracting wool fibers, the phenol must be pure.

Methods

The Estimation of Sulfhydryl Groups in Supercontracted Wool

A sample of wool (10 to 15 mg. for normal merino) wrapped into a bundle, was supercontracted by heating in boiling aqueous phenol (about 100 ml. of a 50% w/w solution) for 10 min. After soaking in a large excess of ethyl alcohol (200 ml.) for sev-

eral hours to remove phenol, the sample was dried and then shaken mechanically with a solution of the color reagent in formamide (10.0 ml.). Reaction is complete in about 24 hr. at 30° C.

To measure the rate of reaction, the supernatant formamide solution was poured off into an absorptiometer cell and returned to the reaction flask after measurement.

Estimation of Sulfhydryl Groups in Pulverized Wool

A sample of wool (about 60 mg.), after soaking in water for 5 min., was pulverized in water (4 ml.) by hand-grinding by means of a pestle and mortar, the mortar being shallow and of 9-cm. diameter. About 30 to 40 min. grinding was usually enough to destroy the fibrous structure of merino wool; about 20 min. was enough for coarse fibers such as mohair. After grinding, the mixture was filtered through a fine porosity, sintered-glass filter–crucible and allowed to dry. Drying was sometimes facilitated by adding pure alcohol and ether.

A small quantity (10 to 15 mg.) of the dry wool powder was shaken for 12 hr. at 30° C. with a formamide solution of the color reagent (10.0 ml.), after which the powder was filtered off and the color intensity of the solution measured. Another sample of powder was used for a moisture determination.

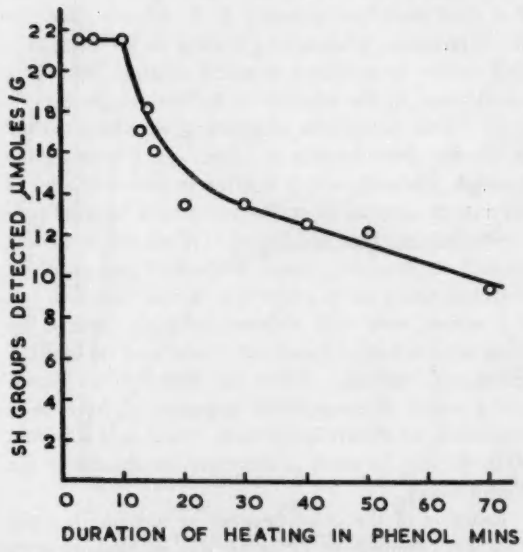

Fig. 1. Relation between the number of sulfhydryl groups detected in supercontracted wool (merino B51.3) and the duration of heating in boiling aqueous phenol.

Microscopic examination of a well-ground sample after reaction showed that the powder consisted of irregular particles with some damaged fibrous segments, but very few that had not been uniformly stained.

Experimental

1. *Experiments on Supercontracted Wool*

a. The effect of the duration of heating in phenol. For these experiments 50% (w/w) aqueous phenol was used at the boil (97.8° C.). Varying the concentration of phenol from 40 to 60% made no difference in the results. A most important factor, however, is the duration of heating in phenol. Figure 1 shows how this affects the number of sulfhydryl groups detected in similar samples of wool; each point refers to the equilibrium value after shaking the sample with excess of the color reagent in formamide at pH 8.0. There is a decrease in the number of sulfhydryl groups detected if heating is continued for more than about 10 min., for reasons that are at present unknown, although the longer the duration of heating, the shorter the time in which equilibrium is reached. This is illustrated in Figure 2 which shows the rate of penetration of the reagent into four samples of wool heated in phenol for 3, 10, 15, and 70 min. Heating for 10 min. is recommended because it allows the most rapid rate of penetration without a decrease in the detectable number of sulfhydryl groups.

For two samples of wool that had been heated in phenol for 10 min., the rate of reaction with the color reagent in formamide was measured over a much longer period than shown in Figure 2, larger amounts of reactants being used to minimize the effect of the measurements. The concentrations of sulfhydryl

TABLE I. The Rate of Reaction of the Color Reagent in Formamide (pH 8.0) with Two Samples of Merino Wool after 10-min. Supercontraction

Sample 1		Sample 2	
Time (hr.)	SH groups (micromoles/g.)	Time (hr.)	SH groups (micromoles/g.)
3.5	16.8	1	3.8
17.5	19.3	4.3	13.6
27.5	19.3	8	18.2
38.5	18.7	11	18.6
49.5	19.3	24	20.8
62.5	19.7	30	21.3
		57	21.4
		96	21.6
		168	22.8
		300	23.9

groups are given in Table I, from which it is apparent that equilibrium is reached in about 24 hr.

b. The specificity of the color reagent for sulfhydryl groups. The specificity of the reagent was investigated by testing wool samples that had been supercontracted for 10 min. and then treated for 4 days at 30° C. with a solution of either mercuric chloride (0.001 *M*, wool to liquor ratio 1:1000); iodoacetamide (0.1 *M*, in pH 8 buffer, wool to liquor ratio 1:250); or N-ethylmaleimide (0.05 *M* in pH 7.4 buffer, wool to liquor ratio 1:250). No reaction, or less than about 0.3 micromoles/g., could be detected with the mercuric-chloride-treated wool, even after 48 hr. For the samples treated with the other blocking agents, a small amount of the color reagent was absorbed in 24 hr., about 3 micromoles/g.

As another check on the specificity of the reagent, a sample of supercontracted wool that had reacted completely with the color reagent was soaked in a solution of cysteine in formamide, the pH of the mixture being 8.8. The color was slowly displaced into the solution, leaving the wool an almost imperceptible pink. No displacement occurred with formamide of the same pH containing no cysteine. This test could not be done quantitatively, nevertheless it indicated that there was little reaction with nonsulfhydryl groups [1, 2].

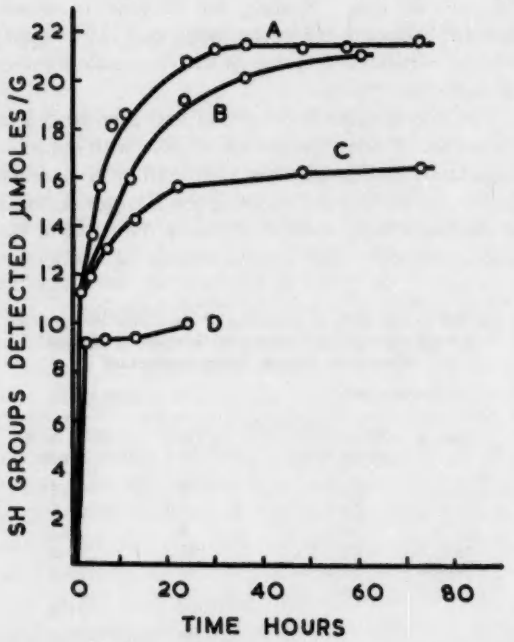

Fig. 2. Rate of penetration of the color reagent into wool supercontracted in phenol for A, 10 min.; B, 3 min.; C, 15 min.; D, 70 min.

c. The effect of cyanide. It is convenient at this stage to consider the effect of cyanide ion on the results for sulfhydryl groups in wool. This is important because in formamide there is always the possibility of traces of Prussic acid, and in aqueous solution this can react with disulfide groups in proteins to give sulfhydryl groups [5]. To ascertain whether such a reaction also occurs appreciably with wool in formamide under the experimental conditions used, an excess of potassium cyanide (about 2 mg.) was added to 10.0 ml. of a formamide solution of the reagent (pH 8.1), which was then used to estimate the sulfhydryl groups in a sample of supercontracted wool. The result, 18.5 micromoles/g., shows that even in excess, cyanide did not produce extra sulfhydryl groups under the experimental conditions used.

2. *Experiments on Pulverized Fibers*

Supercontraction is useful for increasing the rate of penetration of the reagent into wool, but an alternative method is desirable as a check, especially for chemically treated fibers, because some treatments decrease the supercontraction of the fibers [4]. In estimations of the sulfhydryl-group concentrations in human hair, Van Scott and Flesch [9, 10] used hair that had been pulverized. It is known that for wool, however, prolonged grinding in air in a ball-mill causes pronounced chemical changes, including an increase in the number of sulfhydryl groups [6, 7, 8]. This is also true of grinding wool in a mortar in air for short lengths of time. In Figure 3, for example, curve A, which is given in part only, shows the rate of increase of sulfhydryl groups in wool pulverized under these conditions. When the wool was ground in benzene, fewer sulfhydryl groups were detected, and a curve lower than A was followed, but the values were still abnormally high, judged by those obtained after supercontraction, and no limiting value was reached. When the fibers were ground under water, decomposition appeared to have been prevented, as shown by curve B. Grinding for from 30 to 40 min. in water is therefore recommended for merino wool.

Reaction of the color reagent in formamide (pH 8.1) was complete in 12 hr. or less on shaking with pulverized wool at 30° C.; shaking for 24 hr. caused little alteration in the results.

No sulfhydryl groups, or less than 0.3 micro-

moles/g., could be detected in wool that had been pretreated in mercuric chloride solution for 4 days and then ground for 35 min. in water; even after a reaction time of 24 hr.

Results and Discussion

Table II gives data from sulfhydryl-group estimations after supercontraction and after pulverization on a large number of wool samples from a small part of one merino fleece (B51.3). These results were obtained over a period of about 6 months with many different solutions of formamide under the conditions specified. The average values are in good agreement, although both sets of results show a large variation. This was probably due more to errors in the technique than to biological variation, and it was less for estimations done at the same time with the same formamide solution.

In Table III the results of analyses on several wool samples are given; those from analyses on the intact fibers (see Part I) are included for comparison. It is clear that the results obtained from supercontracted and from pulverized wool are similar to those from intact fibers. The individual values for intact fibers did not have the same precision as the others, possibly because of slight variations in the colorimeter during the longer time required for equilibrium to be reached, but the results obtained so far by this method show much less variation.

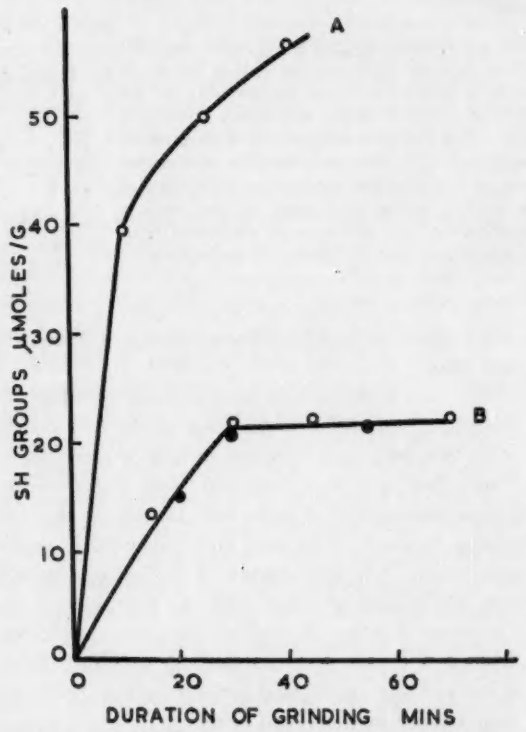

Fig. 3. The effect of the duration of grinding on the number of sulfhydryl groups detected in wool fibers; A, wool ground in air; B, wool ground under water; the full and open circles refer to two sets of experiments.

TABLE II. The Sulfhydryl-Group Concentration in Samples of Wool from Merino B51.3

	After supercontraction	After pulverization
Average SH group concentration (micromoles/g.)	21.2	22.2
Number of estimates	34	34
Coefficient of variation (%)	9.4	23.6
Standard error	0.6	1.0

TABLE III. Sulfhydryl-Group Concentrations in a Number of Wool Samples

Wool	SH groups (micromoles/g.)		
	Intact fibers	Supercontracted fibers	Pulverized fibers
Merino B51.3	21	21.2*	22.2*
Merino Hr1	20	19.0	20.1
		15.0	22.0
		18.3	20.0
			23.0
Merino G5	18	18.3	22.1
		16.9	19.9
Cape mohair	32	29.5	38.7
		32.1	36.7
Merino B51.3 reduced with bisulfite†	42	42.3	43.2
		38.4	44.0
		49.3	

* Average value from Table II.
† Conditions given in Part I.

To conclude, any of the three methods can be used for sulfhydryl-group estimations on normal merino wool. For coarse fibers, pulverization seems preferable, although more work on coarse fibers is desirable. Pulverization also appears to be suitable for chemically modified fibers. Supercontraction may be recommended for rapid results on untreated wool.

Acknowledgments

The author is indebted to Dr. P. C. Carman for his interest and advice, and to Dr. P. Flesch of Pennsylvania University School of Medicine for helpful correspondence.

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Note on the Preparation of a Partial Ester of Cotton Cellulose in Fabric Form

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Abstract

Although cellulose caprates have been made previously, the processes used degraded the cellulose to some extent since the objective was to make products that would be soluble in organic solvents. This paper describes a method of preparing, possibly for the first time, a partial capric ester of cotton cellulose in fabric form, employing conditions that do not degrade the cellulose significantly. The method consists of a presoak in pyridine followed by treatment with capric anhydride. Partial esterification was shown by dyeing characteristics and chemical analysis of the modified cotton; by hydrolysis of the treated fabric and determination of the neutralization equivalent of the isolated capric acid; and by the preparation of a derivative of the capric acid recovered from the fabric. The fabric showed considerable water repellency and some rot resistance.

ALTHOUGH most of the literature concerning esters of cellulose show that the greatest interest has been in highly substituted, soluble esters, the usefulness of partially acetylated cotton [2] indicated that other partial esters of cotton cellulose in fabric form should be investigated. Although cellulose caprates have been made previously, the processes used degraded the cellulose to some extent since the objective was to make products that would be soluble in organic solvents. This paper describes a method of preparing, possibly for the first time, a partial capric ester of cotton cellulose in fabric form, employing conditions that do not degrade the cellulose significantly. Experiments are reported which show that the partially caprylated fabric was free of the acetate. Preliminary evaluation of the properties of the fabric was made.

The cotton fabric was presoaked in pyridine for periods of one hour to nineteen days, best results being obtained with a presoak of four or more hours. The fabric was then removed from the pyridine, passed through a squeeze roll to reduce the wet pickup to about 120%, and then immersed in capric anhydride. The temperature of the anhydride bath was maintained at about 110° C. for about 1 hr. On removal from the treating bath, the fabric was washed in a solvent to remove the unreacted anhydride and any capric acid formed during treatment, then washed in water and dried.

For example, in a typical experiment ¼ sq. yd. of 2-oz. cotton lawn was placed in enough pyridine to cover it and soaked for 4 hr. It was then removed

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and squeezed to a wet pickup of 118.5%. The fabric, still damp with pyridine, was immediately immersed in capric anhydride and held at a temperature of 110° C. The capric anhydride was prepared by reacting acetic anhydride with capric acid in toluene and removing the acetic acid formed and the excess acetic anhydride by azeotropic distillation. After 1 hr. the fabric was removed, extracted with three portions of hot methanol, washed in tap water, and dried. On analysis [3], this fabric showed a 6.6% capryl content, equal to a degree of substitution of 0.07.

Chemical modification of the cotton was shown by a dyeing technique in use at this Laboratory for showing uniformity and approximate extent of acetylation of cotton [2]. The dye bath used contains a blue direct cotton dye which does not color cellulose acetate and a yellow acetate dye which does not color cotton. This technique has been shown to be useful also for the detection of other types of modification of cellulose in which hydroxyl groups have been blocked [5]. Without pyridine pretreatment, fabric soaked in capric anhydride for from three to four days and then washed in methanol still dyed blue with the cotton color, while fabric treated as described above dyed a golden yellow color even after two hours' extraction with methanol in a Soxhlet extractor.

That the product was not a mixed cellulose acetate-caprate was shown by qualitative analysis of the anhydride preparation for acetyl content. The results of this analysis were negative. The caprate was confirmed by hydrolyzing the modified cotton with 2 *N* hydrochloric acid at refluxing temperature until fibers could no longer be seen, and then recovering the freed organic acid by ether extraction. The recovered acid was identified by determination of its neutralization equivalent, using the method reported by Cheronis and Entrikin [1]. This method gave a neutralization equivalent of 171.2 for a known capric acid and 171.5 for the recovered acid. Further identification of the recovered acid was obtained by the preparation of its 2-alkylbenzimidazole by a method reported by Pool, Harwood, and Ralston [4]. This derivative of capric acid is reported to have a melting point of 127° C. [1]. Using a known sample of capric acid, a derivative was prepared having a melting point of 126.5°–127° C. The derivative of the acid obtained from the partially caprylated fabric gave a melting point of 126.5° C. The mixed melting point was 126.5° C. The partially caprylated fabric showed considerably more water repellency than ordinary bleached cotton which is wet readily with water (surface tension of 72 dynes/cm.), while the caprylated fabric required lowering of the surface tension of the wetting liquid to 44 dynes when tested, according to the method of Schuyten, Weaver, and Reid [6]. The warp breaking strength was 32.2 lb. in comparison with 27.9 lb. for the untreated fabric and 27.9 lb. for the fabric that had been merely soaked in pyridine. Contrary to the known favorable effect of long-chain compounds on tear strength when applied as additives to cotton fabric, the Elmendorf warp tear value was 1.0 lb. in comparison with 1.9 lb. for the untreated control fabric and 1.8 lb. for the pyridine-soaked control. The flex abrasion resistance of the treated fabric was 99 cycles in comparison with 1270 cycles for the untreated fabric. The cuprammonium fluidity was 4.3 rhes, while the untreated control was 3.0 rhes, indicating almost no degradation of the cellulose as a result of the treatment. Some rot resistance was shown by a soil burial test in which 98% breaking strength was retained after 11 days, while the untreated control was completely destroyed.

Further work should be done before any general conclusions are drawn concerning the effect on fabric properties of partial esterification of cotton cellulose with higher fatty acids.

Acknowledgment

The authors wish to express their appreciation to Mrs. Alva F. Cucullu for analytical determinations; to Miss Gloria Gautreaux for fluidity values; and to Mrs. Ardis Keller and Miss Janice Poynot for tests of fabric properties.

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The Evaluation of Bacteriostatic Reagents and Methods of Application to Textile Fabrics

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Abstract

Several methods for assessing the extent of bacteriostasis possessed by a treated textile fabric are extant but none is highly objective. The method described in this paper is offered for its relatively high degree of precision and its similarity to the natural function which it is designed to evaluate. Details of the method, of reagent chemical types, and of the effects of concentration of reagent are presented. In addition, results of application of reagents to fabrics in field trials in operating laundry plants is presented. It is demonstrated that this method permits sharp distinction in bacteriostatic efficiency between reagent chemical types, concentrations, and methods of application to textile fabrics.

Introduction

The application of antiseptic agents from solution onto textile fabrics under such conditions that the fabric is rendered bacteriostatic has been the subject of considerable study. Of the methods proposed for determining the degree of bacteriostasis, the agar-plate zone of inhibition technique described by Ruehle and Brewer [3] has enjoyed widest use. Benson and Slobody and their co-workers [1] have used this technique to evaluate the bacteriostatic efficiency of an alkoxy dimethyl benzylammonium chloride (quarternary) in conjunction with clinical observation.

Numerous determinations of bacteriostasis by the agar zone of inhibition technique on samples of fabrics impregnated under varying conditions with bacteriostatic agents of several different formulations failed to produce values which indicated the relative merits of each reagent or method of application.

A quantitative chemical method for the evaluation of bacteriostatic efficiency of antiseptic agents developed by the author is described in this paper. This method involves a determination of ammonia, formed by proteolytic activity, by means of a semimicro Kjeldahl distillation of a standardized urea-citrate medium which has been inoculated with Proteus vulgaris and incubated at 37° C. (98.6° F.) for 18 hr.

The failure of the agar-plate zone of inhibition technique to differentiate the relative merits of various reagents and methods of application is brought sharply into relief in comparison with results obtained with the semimicro ammonia distillation technique. The analytical value of this latter method is attested in the studies which are reported in the paragraphs which follow.

Methods of Assessment

Agar-plate method

This method of test for inhibitory properties has been used to evaluate the antiseptic properties of substances such as salves, dusting powders, sterile pads, and gauzes remaining in contact with the body in the absence of serous body fluids. The test organism ordinarily used is Staphylococcus aureus, but for special purposes the test may be carried out with any organism capable of growing on nutrient agar.

Nutrient agar is melted and cooled, and to this is added 0.1 ml. of a 24-hr. broth culture of the test organism. The inoculated agar is poured into a sterile Petri plate and allowed to harden. The test substance is placed in intimate contact with the surface of the agar.

One and one-half-inch squares of fabric, previously impregnated with the antiseptic agent under test, are placed in intimate contact with the agar. The plates are incubated for 24 to 48 hr. under unglazed porcelain tops at 37° C. (98.6° F.), and then are examined for evidences of inhibition. If the preparation is inhibitory, a zone of clear agar will be noted around the fabric which has been in contact with the agar, the width of the zone indicating the diffusi-

bility of the reagent. If there is no inhibition, growth will be observed adjacent to, and even under the test specimen.

Ammonia distillation method

In this method proteolytic organisms capable of hydrolyzing organic nitrogen compounds in urine or other body excreta are employed. Proteus vulgaris has been used in the work which is reported in this paper. The hydrolysis of natural amino compounds may be represented by the bacteriologically catalyzed reaction given below.

$$(NH_2)_2C = O + H_2O \rightarrow 2NH_3 + CO_2$$

A sterile synthetic urea medium is used to provide a standard nitrogen source. Sections of fabric measuring 200 sq. in., which previously have been impregnated with the reagent under test, are wet out with 75 ml. of a urea-citrate medium which has been inoculated with a test organism. The medium has the following composition.

Component	Grams per liter
Urea (98.6% purity)	10.00
Sodium citrate, c.p.	4.00
Dipotassium hydrogen orthophosphate, c.p.	0.30
Magnesium sulphate, c.p.	0.10
Calcium chloride, c.p.	0.10
Sodium chloride, c.p.	0.10
Yeast (Difco)	0.50

The purity of the urea was determined by micro Kjeldahl distillation. Sterilization of the medium is accomplished in the following manner. The urea is dissolved in water and made up to 100 ml. in a volumetric flask. It is sterilized by Seitz filtration (ultrafiltration). The remaining materials are dissolved in 900 ml. of water and steam-sterilized in an autoclave for 15 min. at a steam pressure of 13 to 15 lb./sq. in. gauge, equivalent to a condensing temperature of 118.7° to 121.0° C. (246° to 250° F.). The two solutions then are combined aseptically.

The fabric sections wet out with the urea-citrate medium are placed in sterile Mason jars, loosely capped, and incubated for 18 hr. at a temperature of 37° C. (98.6° F.), after which time the medium is extracted from the fabric, and a semimicro Kjeldahl distillation is performed to assay for ammonia. The per cent inhibition then is calculated from the ammonia produced when untreated sections of fabrics of the same size are run in a similar manner as controls. The following expression is used to calculate the per cent inhibition.

$$\text{Per cent inhibition} = \left(\frac{U - X}{U - C}\right) 100$$

where

U = weight of ammonia produced in untreated fabric,

X = weight of ammonia produced in treated fabric,

C = weight of ammonia produced in uninoculated control.

Type and Composition of Compounds Used

Four general classes of organic reagents have been studied as bacteriostatic agents. In the following paragraphs the composition of these reagents is presented briefly.

The quaternary ammonium compounds

These compounds had their earliest development in conjunction with finishing treatments for fibrous materials. Uses for these compounds were as textile finishing agents for softening, dye bath leveling, and similar products. Recently, it has been noted by many investigators that certain of these compounds have notable fungicidal and bacteriostatic properties.

Commercial production of these materials follows classical lines for the preparation of quarternary ammonium salts. The compounds generally are built from the secondary amine to the tertiary amine; then the quaternary ammonium salt is made using an alkylating material such as methyl or ethyl sulfate. The literature at the present time catalogs thousands of these quaternary ammonium compounds. Their uses range from surface-active agents and cation-active detergents, textile softeners, and penetrating and leveling agents for textile finishes, down to bacteriostatic and fungicidal agents. The general formula is $RNR'R''R'''X$, where R, R', R'', and R''' represent alkyl, alkylaryl, or alkoxyl groupings, and X represents a halide grouping. Most frequently two or three of the R groupings are simple alkyl groups such as methyl or ethyl, with one of the R groups representing a C_6 to C_{20} hydrocarbon residue obtained generally from some vegetable fat source such as cocoanut oil. The oils are extracted and fractionated at reduced pressure, but are utilized as an alkylate mixture ranging generally from 8 to 18 carbon atoms chain length. Frequently one of the R groups is an alkylaryl group.

During the course of this work seven different commercially available ammonium salts were em-

ployed. Since these compounds are rather complex in character, they have been listed in subsequent tables as Quaternary (*1*), Quaternary (*2*), and so forth. The identity of each of these quaternaries is given below:

Quaternary (*1*)—alkyl (C_8H_{17} to $C_{18}H_{37}$, principally $C_{12}H_{25}$) trimethyl ammonium chloride; 75 weight per cent active in 2-propanol.

Quaternary (*2*)—alkyl (C_8H_{17} to C_{18}, principally $C_{18}H_{33}$) trimethyl ammonium chloride; 33 weight per cent active in water.

Quaternary (*3*)—para-diisobutylcresoxyethoxyethyl dimethyl benzyl ammonium chloride; 100 per cent crystals.

Quaternary (*4*)—para-diisobutylphenoxyethoxyethyl dimethyl benzylammonium chloride; 25 weight per cent active in water.

Quaternary (*5*)—methyl dodecylbenzyl trimethyl ammonium chloride; 50 weight per cent active in water.

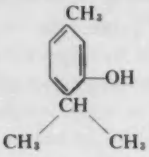
Quaternary (*6*)—alkyl (C_8H_{17} to $C_{18}H_{37}$) dimethyl benzyl ammonium chloride; 10 weight per cent active in water.

Quaternary (*7*)—alkyl (C_8H_{17} to $C_{18}H_{37}$)-3,4-dichlorobenzyl dimethyl ammonium chloride; 50 weight per cent active in water.

Thymol

The homologs of phenol have varying degrees of antibacterial activity. Phenol has been in general use as a germicide for many years. Mixtures of cresols with various soaps give soluble disinfectants (lysol, cresoline). Resorcinol (meta-dihydroxybenzene) produces considerable surface tension depression, and is used widely as a germicide.

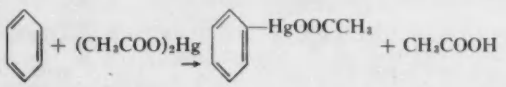
Thymol, an isomer of carvacrol, is available from coal and wood tar and from essential oils. It is readily available from oil of thyme. Its structure is that of a homolog of phenol, being



The Mercurials

According to Whitmore [5], mercury derivatives are known for every type of aromatic hydrocarbon. The mercurials most widely used in antiseptic and germicidal areas are aromatic halide or acetate derivatives.

These are made most frequently by direct mercuration of benzene by mercuric acetate in alcohol solution.



Treatment of the phenyl mercuric acetate with halide solutions produces the phenyl mercuric halide. Another method for introducing mercury into an aromatic nucleus is through the interaction of phenylsulfinic acid and mercuric chloride.

High Molecular Weight Amines

These compounds have been in use for a number of years as fungicides and mildewproofing agents. They are manufactured generally by degradation of acid amides by hypochlorite or hypobromite solu-

TABLE I. Inhibition of Ammonia Production of Bacteriostatic Reagents at Various Dilutions
Evaluations made by ammonia distillation technique

Bacteriostatic reagent	Per cent active ingredient	Per cent inhibition at indicated dilution (Based on reagent as received)							
		1:2,500	1:5,000	1:10,000	1:20,000	1:40,000	1:100,000	1:200,000	1:400,000
Quaternary (*1*)	75	—	99.8	100	—	100	100	—	100
Quaternary (*2*)	33	—	100	100	—	100	100	—	100
Quaternary (*3*)	25	100	96.1	95.4	97.8	92.2	51.9	47.8	36.0
Quaternary (*4*)	100	—	100	100	—	100	99.2	—	80.9
Quaternary (*5*)	50	—	100	100	—	100	47.4	—	—
Quaternary (*6*)	10	100	100	98.3	94.7	96.0	87.1	27.0	4.5
Quaternary (*7*)	60	—	95.4	100	95.3	96.3	84.8	87.4	19.2
Thymol	7.5	100	96.1	100	97.8	98.4	91.1	50.4	32.6
Phenyl mercuric acetate	3	100	99.7	97.6	91.0	96.0	—	88.5	100
Dodecylamine	40	100	98.8	97.6	96.3	99.1	91.8	60.0	13.7

tions. Commercially the fatty acids are converted to the amide, and then degradation takes place to the amine.

The Effect of Concentration on the Bacteriostatic Efficiency of Reagents

The Effect of Concentration of Bacteriostatic Reagent as Determined by Direct Dilution

The practical value of the chemical method for measuring ammonia production during the bacterial breakdown of urea was investigated by a series of studies using bacteriostatic agents aforementioned, both in solution and when applied to textile fabrics.

In this part of the work, the technique was applied to the direct evaluation of the effect of reagent concentration, by adding the reagent to sterile urea-citrate medium in a series of dilutions ranging from 1:2,500 to 1:400,000, and assessing the results by the chemical technique developed in this study.

One-hundred-ml. portions of the medium were placed in 300-ml. Erlenmeyer flasks, and the bacteriostatic reagent added in such quantity as to produce the desired dilution. Control samples of the medium containing no reagent were prepared at the same time. One-ml. portions of the seed inoculum were added from sterile transfer pipettes. The samples, which were plugged with sterile cotton, then were incubated at 37° C. (98.6° F.) for a period of 18 hr., at the end of which time they were withdrawn and evaluated by the method of ammonia distillation. Table I and Figure 1 give the results of trials on seven different quaternary ammonium compounds, an alcoholic solution of thymol, phenyl mercuric acetate, and a solution of dodecylamine in monoethyl ether of ethylene glycol.

The striking feature of the data in the preceding table is the fact that all reagents were almost completely inhibitory in solution, up to a threshold concentration of about 1:100,000. Therefore it is possible to make clear, sharp distinctions in the efficacy of bacteriostatic agents and to determine the threshold concentration of any given bacteriostatic material by this technique.

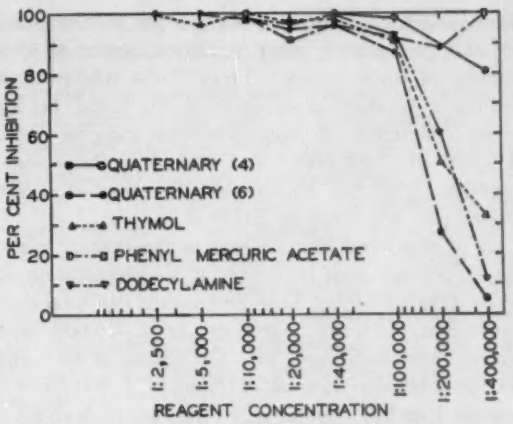


Fig. 1. Inhibition of ammonia production at various dilutions.

It should be noted in passing that the efficiency with respect to bacteriostasis of the phenyl mercuric acetate is undiminished even at a concentration of 1:400,000. This parallels the generally known bactericidal action of mercury and other heavy metals. Although it is beyond the scope of this work to discuss the physiological factors involved in the use of mercurial and other heavy metal compounds as bacteriostatic and germicidal materials, there are some who do not recommend the use of these reagents because of the possible toxicity factors involved.

The quaternary ammonium salt para-diisobutylphenoxyethoxyethyl dimethyl benzyl ammonium chloride is widely sold to marketing and distributing

TABLE II. Inhibition of Ammonia Production of Various Tinctorial Strengths of *p*-Diisobutylphenoxyethoxyethyl Benzyl Dimethyl Ammonium Chloride at Various Dilutions

Evaluations made by ammonia distillation technique under the following conditions: medium = urea-citrate; organism = Proteus vulgaris; time = 18 hr.; temperature = 37°C (98.6°F)

Brand	Reagent tinctorial strength, per cent	Per cent inhibition at indicated dilution (Based on material as received)							
		1:2,500	1:5,000	1:10,000	1:20,000	1:40,000	1:100,000	1:200,000	1:400,000
No. 1	100	—	100	100	—	100	99.2	—	80.9
No. 2	100	—	99.3	100	—	100	100	—	84.8
No. 3	25	—	94.4	100	95.0	96.6	78.2	42.2	—
No. 4	24	100	98.8	100	96.3	95.6	81.1	49.6	46.6
No. 5	10	—	100	100	—	73.3	—	—	—

firms which resell this material as the pure crystals, or as concentrated water solutions, under a wide variety of trade names. Tests of the inhibition of ammonia production of each of the listed brands were conducted at concentrations ranging from 1:2,500 to 1:400,000. The results of these tests, together with the known concentration of active ingredient, are listed in Table II.

It is of interest to note that in the case of brand no. 4, the per cent inhibition at a concentration of 1:100,000 is 81.1%. This corresponds to a total concentration of active ingredient of 1:416,000, and agrees remarkably well with the figures of 80.9 and 84.8% inhibition at total dilutions of 1:400,000 for brands 1 and 2. Similarly, in the case of brand no. 5, an inhibition of 73.3% is obtained at a total dilution of 1:400,000.

The character of the curves shown in Figure 1 suggests that inhibitory action of bacteriostatic agents (or ability of bacterial organisms to grow in the presence of inhibitory substances) is not a smooth function of reagent concentration. Note that a semi-log plot fails to straighten the curves.

The Effect of Concentration of Reagent on the Bacteriostatic Efficiency of Fabrics Impregnated with Various Reagents

A second method under discussion for evaluating the chemical test method of ammonia formation and for determining the relative merits of the reagents under test was through the use of standard birdseye fabrics impregnated with each reagent at concentrations ranging from 1:1,000 up to 1:100,000.

The reagent solutions were prepared in 4000-ml. beakers at concentrations of 1:1,000, 1:2,500, 1:5,000, 1:10,000, 1:25,000, 1:50,000, and 1:100,000. Fabric specimens measuring 12.5 by 16 in. (area 200 sq. in.) were immersed in the reagent solutions and allowed to soak for a period of 2 hr. at 25° C. (77° F.). The contents of each beaker were stirred occasionally. The samples were removed and allowed to air-dry. They then were examined for their degree of inhibition to ammonia production, assay being made by the ammonia distillation technique. Table III and Figure 2 summarize the results of these tests.

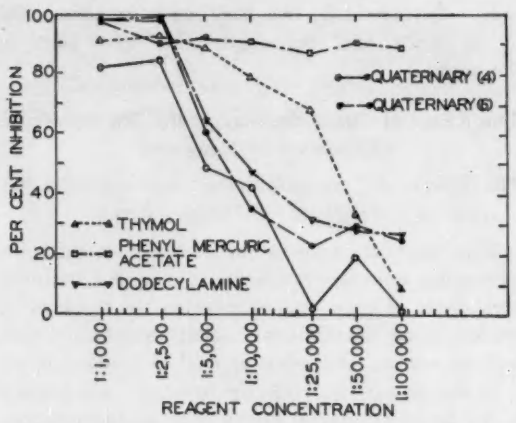


Fig. 2. The effect of reagent concentration on inhibition of ammonia production of fabrics impregnated with bacteriostatic reagents.

The apparent threshold concentration for the two quaternary ammonium compounds and the primary amine in this instance was found to lie approximately at 1:2,500. In the case of thymol, the threshold lies between 1:5,000 and 1:10,000. Phenyl mercuric acetate maintains nearly complete inhibitory action out to a concentration of 1:100,000. The erratic character in the case of quaternary (*4*) at higher dilutions may be attributable to uneven adsorption of the reagent from the bath. This anomalous behavior of quaternary ammonium compounds impregnated on textile fabrics persists throughout the data

TABLE III. The Effect of Reagent Concentration on the Bacteriostatic Efficiency of Textile Fabrics Impregnated with Chemical Agents

Cotton birdseye fabrics immersed for 2 hr. at 70°F. Evaluations made by ammonia distillation technique.

Bacteriostatic reagent	Per cent inhibition at indicated dilution (Based on reagent as received)						
	1:1,000	1:2,500	1:5,000	1:10,000	1:25,000	1:50,000	1:100,000
Quaternary (*4*)	81.9	83.9	48.3	41.8	1.6	18.9	1.0
Quaternary (*6*)	98.1	97.7	60.0	34.7	22.9	29.6	24.7
Thymol	90.9	92.2	68.3	78.6	67.8	32.9	8.3
Phenyl mercuric acetate	96.7	89.8	91.7	90.3	86.9	90.1	88.3
Dodecylamine	98.1	98.1	63.7	46.3	30.9	28.1	25.6

presented, and has been found in commercial practice when these reagents are used as bacteriostatic agents.

The Effect of Fabric Type on the Bacteriostatic Efficiency of Chemical Reagents Applied to Textile Fabrics

A series of tests based on the ammonia distillation technique was conducted to determine the effect of fabric type on the bacteriostatic character of the impregnated fabrics. Quantities of typical cotton birdseye (diaper cloth) and cotton sheeting were utilized in these evaluations.

The birdseye and sheeting used in these tests had the following construction characteristics:

	Birdseye	Sheeting
Fiber	cotton	cotton
Weave	birdseye	plain
Threads per inch, warp	62	79
filling	54	70
Twists per inch, warp	26	24
filling	13	15
Ply of yarns, warp	1	1
filling	1	1
Ounces per square yard	3.1	3.1

The major differences in these fabrics appear to lie in the weave type, thread count, and yarn weight. The yarn weight differs by virtue of the fact that a total of 116 warp and filling yarns, in the case of the birdseye cloth, have about the same weight as 149 total warp and filling yarns in the case of the sheeting. In every case, 200 sq. in. of fabric (12.5- by 16-in. sections) were used in the tests to be described.

The Effect of Fabric Type at Various Concentrations of Bacteriostatic Reagent

Parallel impregnations were made in the laboratory on the birdseye and sheeting fabric samples; the fabrics were immersed for a period of 2 hr. with occasional stirring, at a temperature of 25° C. (77° F.), in 4000-ml. beakers, each containing the reagent in one of the following concentrations: 1:1,000, 1:2,500, 1:5,000, 1:10,000, 1:25,000, and 1:100,000. The fabrics then were allowed to air-dry. The two fabric types were treated in separate beakers. The fabrics then were subjected to tests for ability to inhibit ammonia production. The results are given in Table IV.

Marked differences between the two fabrics are not evident from examination of the data in Table IV. The sheeting appears to have slightly greater bacteriostatic efficiency in the case of quaternary (*4*) and of the phenyl mercuric acetate. The birdseye fabric, on the other hand, exhibits slightly greater bacteriostatic efficiency in the case of quaternary (*6*), thymol, and dodecylamine.

It is noteworthy that results are erratic at elevated dilutions for both quaternary ammonium compounds, undoubtedly because of uneven impregnation.

The findings of this part of the study confirm the opinion of Fessler [2] that, under different conditions, different amounts of surface-active material are absorbed on different surfaces. Since the two types of cloth ranked differently in ammonia production when impregnated with the different reagents, it is evident that both the cloth and the reagent were

TABLE IV. The Effect of Fabric Type on the Bacteriostatic Efficiency of Textile Fabrics Impregnated with Chemical Agents

Fabrics immersed for 2 hr. at 70° F. Evaluation by ammonia distillation technique.

Bacteriostatic reagent	Fabric type	Per cent inhibition at indicated dilution (Based on reagent as received)						
		1:1,000	1:2,500	1:5,000	1:10,000	1:25,000	1:50,000	1:100,000
Quaternary (*4*)	Birdseye	81.9	83.9	48.3	41.6	1.6	18.9	1.0
	sheeting	95.1	95.2	60.4	51.2	14.0	17.9	9.2
Quaternary (*6*)	Birdseye	98.1	97.7	60.0	34.7	22.9	29.6	24.7
	sheeting	94.9	94.5	25.2	4.4	0	13.7	10.3
Thymol	Birdseye	90.9	92.2	88.3	78.6	67.8	32.9	8.3
	sheeting	95.8	95.6	73.4	64.7	33.2	14.9	4.3
Phenyl mercuric acetate	Birdseye	96.7	89.8	91.7	90.3	86.9	90.1	88.3
	sheeting	98.9	98.9	97.7	99.9	99.4	99.3	99.6
Dodecylamine	Birdseye	98.1	98.1	63.7	46.3	30.9	28.1	25.6
	sheeting	97.0	89.5	21.3	15.8	14.0	37.0	8.7

involved in the degree of bacteriostasis produced, even in systems in which all factors except the type of cloth were the same.

Studies of the Application of Bacteriostatic Agents to Commercial Laundry Procedures

The material presented above has been obtained in conjunction with fabrics treated under rigid conditions of laboratory control. In addition, the ammonia distillation method of assessing bacteriostasis has been used in conjunction with field trials in commercial laundry plants concerned with minimization of ammonia production in soiled diapers and fouled bed linens. Some variations in methods of application of bacteriostatic agents are considered in the following paragraphs.

The Effect of pH of Application on Ammonia Production in Textile Fabrics Impregnated with Bacteriostatic Reagents

The relationship of pH to the efficacy of representative bacteriostatic agents applied to diaper fabrics was studied under field conditions, using fabrics impregnated under controlled conditions. The treated fabrics then were immersed in sterile urea-citrate medium, inoculated with the test organism, and incubated at 37° C. (98.6° F.) for a period of 18 hr. The ammonia produced was assayed by the ammonia distillation technique. Bacteriostatic reagents were applied to the fabrics in a commercial laundering plant under conditions of careful control, as hereinafter outlined.

The fabrics were given a standard laundering, consisting of three separate 10-min. soaping operations followed by six 5-min. rinses. The bath following the sixth rinse, known as the sour bath, is one generally included in the laundry procedure, whereby the final traces of alkaline materials, which cannot be removed by the successive dilution of the rinsing operations, are neutralized by the addition of a small quantity of an acid or acid salt, known as a sour in the laundry field. This results in a final pH of the fabric of about 5.0 to 5.5.

In one series of tests, the bacteriostatic reagents were added directly during the sour operation to a calculated concentration of 1:5,000, based on the sample as received. The time of impregnation was 5 min. The load size was 400 ± 25 lb. of fabric.

In a second series of tests, the sour bath was drawn off and the reagent added at a concentration of 1:5,000 to a separate rinse following the sour bath.

In a third series of tests, the sour bath was drawn off, the contents of the washer were flushed with tap water, and the reagents again were added in a concentration of 1:5,000, following this intermediate rinsing operation. Samples were withdrawn at the completion of the washing procedure and reserved for assay.

The data are summarized in Table V.

It will be noted from examination of Table V that there is a considerable increase in the general level of bacteriostasis achieved in progressing from Part *A* to Part *C* of the table. When the reagents are added directly to the sour bath, generally poorer results are obtained.

TABLE V. The Effect of pH of Application on the Inhibition of Ammonia Production of Textile Fabrics Impregnated with Bacteriostatic Reagents

Cotton birdseye fabrics impregnated in a commercial laundry plant; bacteriostatic reagent added in a concentration of 1:5,000. Evaluations made by ammonia distillation technique.

Bacteriostatic reagent	Part *A*: Reagents added to alkali-neutralizing (sour) bath			Part *B*: Reagents added in rinse following alkali-neutralizing (sour) bath			Part *C*: Reagents added in rinse following a flush, following alkali-neutralizing rinse		
	Temperature (°F.)	pH	Per cent inhibition	Temperature (°F.)	pH	Per cent inhibition	Temperature (°F.)	pH	Per cent inhibition
Quaternary (*3*)	93	5.3	0.9	90	5.3	31.3	86	6.8	52.0
Quaternary (*4*)	90	5.7	21.1	92	5.9	14.7	93	6.7	58.2
Quaternary (*5*)	96	6.8	35.0	90	5.3	0.0	89	6.8	84.5
Quaternary (*6*)	93	6.5	4.2	90	6.3	38.0	92	7.1	52.0
Quaternary (*7*)	90	5.9	23.4	91	6.4	17.4	92	6.8	66.6
Thymol	96	6.9	22.0	92	6.9	22.0	90	7.3	87.1
Phenyl mercuric acetate	93	5.7	65.5	93	7.7	72.1	89	6.3	100
Dodecylamine	93	5.1	38.0	91	6.3	25.3	93	6.7	49.8

The following summary shows the trends established by the data in Table V.

Reagents added to	Average temperature (°F.)	Average pH	Average per cent inhibition
Part *A*: Sour	93	5.9	26.3
Part *B*: Rinse following sour	91	6.3	27.6
Part *C*: Rinse following flush following sour	90	6.8	63.8

It is suggested by the trends shown above that the inhibition shown by all reagents increases as the pH of application of the reagents increases. There is still another factor, however, which may enter into consideration. It is known that quaternary ammonium compounds are incompatible with anionic detergents of the type of sodium stearate, sodium palmitate, and sodium oleate. This is ascribed to loss of ionic character through interaction of active groups, since the quaternary ammonium salts are compatible with nonionic detergents. It may be possible, therefore, that the presence of residual quantities of such anionics as soap or synthetic detergents in the sour bath is responsible for partial or total destruction of the bacteriostatic properties of these reagents. The utilization of additional rinsing may, by the mechanical process of dilution, remove additional residual quantities of interfering components from the washer, with the result that the reagent affords even greater inhibitory power to ammonia production.

Note that in the case of the conditions where a high level of bacteriostatic efficiency has been achieved, the general rank order of reagents is phenyl mercuric acetate, thymol, quaternary (*4*), quaternary (*6*), and dodecylamine. In the case of laboratory impregnations at a concentration of 1:5,000, the order of effectiveness is phenyl mercuric acetate, thymol, dodecylamine, quaternary (*6*), and quaternary (*4*).

Studies of the Diffusibility of Bacteriostatic Reagents

In one series of tests conducted in a commercial plant, the degree of impregnation achieved throughout the entire load was examined. This factor was determined by selecting fabrics from the periphery and from the center of the load of fabrics being laundered. The tests were made in the following manner.

The formulary sequence was the same as that outlined previously, and the reagents were added in a concentration of 1:5,000 in a separate rinse following a flush with tap water, in turn following the sour bath. When the washer was opened, samples were taken from the exterior of the load. Samples then were selected after one half of the load had been removed from the machine.

In this particular plant, soiled diapers were being washed in unit loads of 400 ± 25 lb. Under these circumstances about 3000 diapers are contained in roughly 65 cu. ft. of space. When completely wet out, these fabrics traveled essentially as a unit, that is to say, any one fabric remained stationary with respect to any other fabric in the load. Samples selected from the top of the load when the washer is opened may be expected to be outside samples; similarly, those selected when one half of the load has been removed would reasonably represent the center of the mass. The specimens were coded and were reserved for assessment of bacteriostasis. The results are listed in Table VI.

Examination of Table VI shows that diffusion of these reagents is not complete during the 5-min. period of treatment; the degree of diffusion varied considerably with the reagent. Center-of-load specimens of quaternary (*6*) and phenyl mercuric acetate both exhibited at least two thirds the inhibitory action of the outside specimens. In all other cases the center specimens showed less than one half the inhibitory power of the peripheral samples.

These differences may be attributed to two causes: (*a*) there is relatively poor diffusion into the center

TABLE VI. The Diffusibility of Several Bacteriostatic Reagents

Cotton birdseye fabrics impregnated in a commercial plant. Bacteriostatic reagent added in a concentration of 1:5,000. Evaluations made by ammonia distillation technique.

Bacteriostatic reagent	Per cent inhibition of fabric	
	Outside of load*	Center of load†
Quaternary (*3*)	52.0	23.8
Quaternary (*4*)	58.2	0.0
Quaternary (*5*)	84.5	0.0
Quaternary (*6*)	52.0	41.1
Quaternary (*7*)	66.6	26.5
Thymol	87.1	37.8
Phenyl mercuric acetate	100	65.5
Dodecylamine	49.8	9.5

* Diapers for test were selected from outside of load of fabrics in washer.

† Diapers for test were selected from approximately the center of load of fabrics in washer.

of the load, with the result that less reagent is available to impregnate fabrics at the center of the load; and (*b*) the fabrics on the outside of the load exhaust the reagent from the solution to the extent that there is not sufficient concentration of reagent at the center to provide the level of inhibitory power found on outer fabrics. It is probable that some combination of these two factors is responsible for these differences.

These data indicate the necessity of applying bacteriostatic agents to textile fabrics which are packed only very lightly in a container, so that equal opportunity of penetration of all parts of a textile load may be effectuated.

Summary

The application of a quantitative chemical method to problems of evaluation of bacteriostatic reagents and of methods of application is described. The method utilized involves determination of ammonia formed by proteolytic activity, by means of a semimicro Kjeldahl distillation of a standardized urea-citrate medium which has been inoculated with Proteus vulgaris and incubated at 37° C. (98.6° F.) for 18 hr.

The precision of the method and the specificity is indicated in comparison with former methods of assessment. Detailed procedures and results using four distinct classes of chemical compounds in direct dilution and impregnated on textile fabrics are given. The effect of chemical type, reagent concentration, and fabric type is presented.

Studies of the application of this technique to the determination of bacteriostasis of textile fabrics in field trials in commercial plants also are included.

Acknowledgment

The generous financial assistance of the Diaper Service Institute of America has made possible the completion of this work, and sincere thanks are extended to this organization by the author.

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Manuscript received December 21, 1955.

Correction for April TRJ

In the article, "The Application of Electron Microscopy to Synthetic Fiber," by R. G. Scott and A. W. Ferguson, in the April issue of TRJ, the photograph which appeared with the Fig. 1 legend belongs with the Fig. 26 legend, and vice versa.

The legend with Fig. 26 should read ". . . *after* the solvent treatment," and the legend with Fig. 27 ". . . *before* solvent treatment."

Letters to the Editor

Short communications in the form of Letters to the Editor are intended to provide prompt publication of significant new research results and to permit an exchange of views on papers previously published in the JOURNAL. These communications are not submitted to formal review as are research papers, and the editors do not assume any share of the author's responsibility for the information given or the opinions expressed. When work previously published in the JOURNAL is the subject of critical comment, the authors of the original paper are given an opportunity to submit a reply, which will be published concurrently when possible.

An Evaluation and Comparison of Evenness Testers

Swiss Federal Institute of Technology
Zurich, Switzerland
February 14, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

In the August 1955 issue of your Journal, p. 686, you published an article by William T. Waters, "An Evaluation and Comparison of Evenness Testers." As several different evenness testers are being manufactured, comparative tests showing how the various instruments agree with each other and what special merits each tester can claim are certainly desirable.

It is, however, disappointing that the Uster evenness tester submitted to the comparative tests was a Model A, the first model to be made. The production of this model was stopped as long ago as 1950, since which date Model B has been available. If the new Uster tester, Model B, had been tested, the results would have shown important differences.

It is not my intention to discuss the article extensively, but I should like to draw attention to some of the more important points of disagreement.

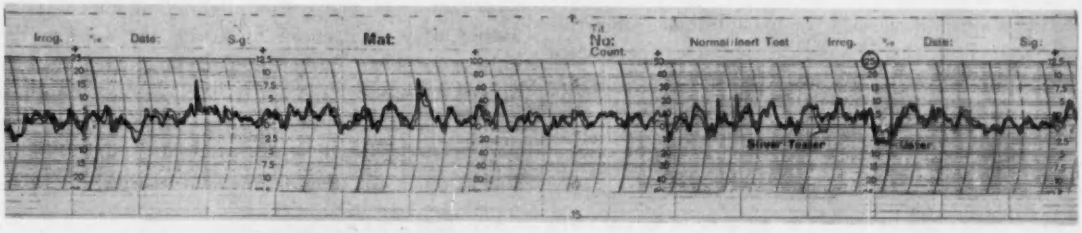
In Table II on p. 687, "Yarn Characterization Test," very different yarn lengths have been tested; the results obtained, therefore, are not comparative and hardly entitled to characterize the yarn.

In Figure 6 on p. 690 a considerable influence of the yarn speed on the precision of results is registered. This would certainly not have been the case on Model B, but according to our experiences, it is surprising also for the tester Model A.

Again, as to Figure 4 on p. 689, the coefficient of variation obtained is influenced by the gain employed. A divergence of this kind would not have been registered on the Uster Model B instrument.

The warmup period registered in Figure 15 is approximately 45 min. This has been reduced to 10 min. on the Model B instrument.

We further are impressed by the very low correlation coefficients shown in Table VII for the Uster evenness tester. Comparative tests carried through with the Saco-Lowell sliver tester are shown on the attached diagram, where the two curves have been drawn on the same chart; it will be seen that the



Consistency of the indication of the sliver tester and the indication of the Uster evenness tester.

agreement between the purely mechanical testing device and the electronic Uster Model B instrument is very near to perfection.

The great improvements achieved by the Model B instrument, compared with its predecessor, are shown clearly by the following table.

	Uster evenness tester	
	Model A	Newest model B
Warmup period	30–60 min.	10 min.
Stability at medium gain	Divergence 5–20%/hr.	Divergence less than 2%/hr.
Precision of yarn measurement referring to the mean value	Error maximum ±8%	Error below ±2%
Yarn speed maximum	8 yd./min.	100 yd./min.
Limit frequency of the testing instrument	10 cps	175 cps
Limit frequency of recorder	1,5 cps resp. 5 cps	25 cps

EMIL HONEGGER

Courtaulds (Alabama), Inc.
Mobile, Alabama
January 24, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

At the time of the experimental work for the article, "An Evaluation and Comparison of Evenness Testers," the Uster Model A tester was the only model available at the Institute of Textile Technology, and requests were made to the Uster Corporation for use of their newer model, but these requests were not granted. However, the purpose of the work was not a competitive comparison of the various evenness testers, but a comparison of results and faults which one might encounter using these instruments. Also, at that time, the majority of the people were using the Model A tester and quite a few still do.

W. T. WATERS

Second-Order Transition Temperature and Fiber Properties

Swedish Textile Institute
Gothenburg, Sweden
January 17, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

In a paper published in the November 1955 issue of this Journal, pp. 891–901, Alexander Brown gives a presentation of some experiments concerning the second-order transition temperature and fiber properties. The experimental results concerning stiffness-temperature behavior are given in his diagrams Figures 5 through 11. The author finds it necessary to use a logarithmic scale for the stiffness. Since this necessity is neither theoretical, nor does there seem to be a practical reason for this way of representation, we have transferred the measured values from the curves given in the paper to linear coordinates. These new curves are given in Figures 1 through 3. The surprising result is that the conclusions which have been drawn in the paper seem to fit to the form of the curves given in the paper, if that ordinate is looked upon as linear. The curves transferred to a linear ordinate give a quite different result. For instance the Dacron [1] curve in Figures 6 and 10 of the paper is said to have a second-order transition temperature at about 80° C., where a drop-off is observed by the author in the logarithmic scale curve. In the linear coordinates, as seen from Figure 1, there is no change in the steepness of the curve at this temperature. From Figure 7, the author in good agreement with his theoretical opinion, finds that of three acrylic fibers, Orlon,[2] as the most crystalline, gives the least drop-off in stiffness at the second-order transition temperature. In the linear diagram the result is the converse. One more example may be given from the nylon curve. The author finds a drop-off at about 45° C. In the linear-coordinate curve there is no visible second-order transition point. It is therefore doubtful whether stiffness measurements are adequate for the determination of second-order transition points. For instance, the found agreement between the mini-

[1] Du Pont polyester fiber.
[2] Du Pont acrylic fiber.

mum of the resiliency curves and the second-order transition points of the stiffness seems to be disturbed in the linear-stiffness diagrams.

TRYGGVE EEG-OLOFSSON

Bakelite Company
Bloomfield, N. J.
January 31, 1956

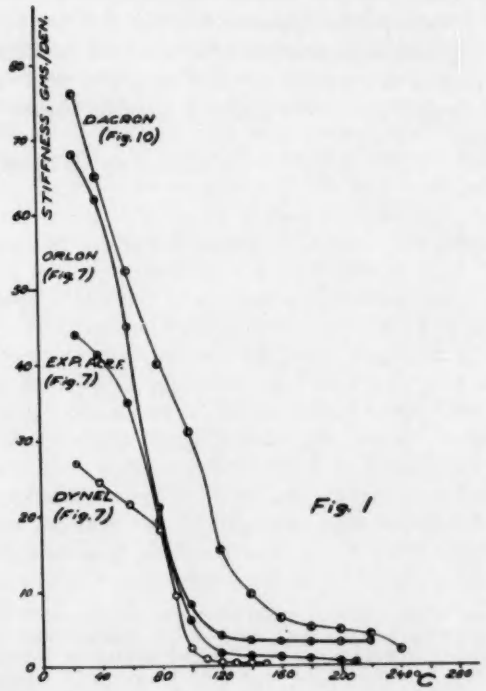
To the Editor
TEXTILE RESEARCH JOURNAL

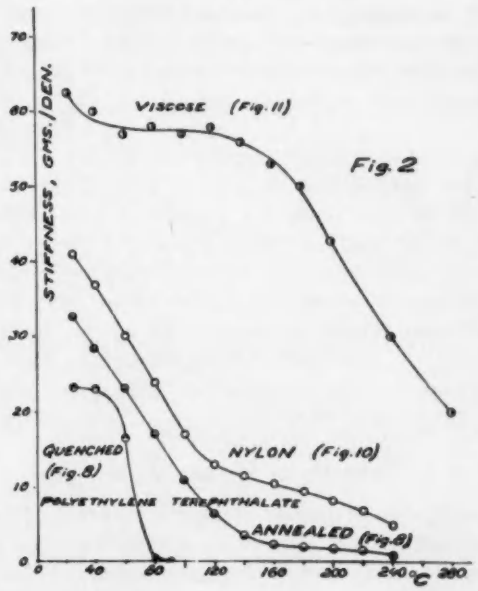
Dear Sir:

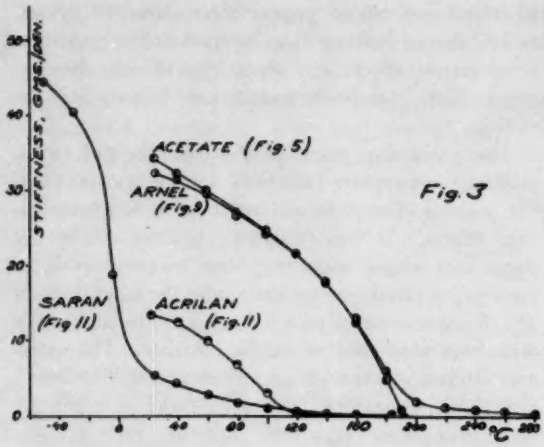
The use of the term "stiffness" rather than that of "logarithm of stiffness" in the text of my paper in the November 1955 issue of the Journal is, perhaps, unfortunate, leading as it did, to the literal treatment as presented by Eeg-Olofsson. However, the logarithmic scale is the correct one to use because it affords equal sensitivity to all stiffness values. The linear scale compresses the low stiffness values, below about 2 g./den., beyond recognition, and these values are of extreme importance with many polymers. Also, the linear scale emphasizes the very high stiffness values, greater than about 40 g./den. which derive neither from second-order transition temperature effects nor from crystallinity, but instead, from previous mechanical history of the sample.

The particular cases of the Dacron and nylon stiffness-temperature behaviors are the poorest from the point of view of second-order transition temperature effects. It was repeatedly pointed out in my paper that second-order transition temperature is an amorphous phase phenomenon, and the magnitude of the effects associated with it is greater the higher the amophous-phase content of the polymer. The nylon and Dacron (both commercial continuous filaments) are highly crystalline polymers; there is relatively little amorphous phase and therefore little second-order transition temperature effect. Even with the logarithmic scale figures the change in (logarithm of) stiffness is very gradual, diffuse, and difficult to pinpoint. On the other hand, the less crystalline (quenched) Dacron shows a pronounced drop in both stiffness and the logarithm thereof, in the second-order transition temperature region. A quenched nylon should certainly show a similar increased effect over that of the highly crystalline commercial nylon fiber.

The stiffness of a polymer above its second-order transition temperature is a function of the degree







of crystallinity of the polymer; the stiffness below the second-order transition temperature is a function of the previous mechanical history of the polymer. The continuous filament Orlon, with its stiffness of about 70 g./den. at room temperature, has had quite a history; it is a highly oriented fiber. The commercial Dynel is less oriented and its stiffness is much lower, about 30 g./den. at room temperature. Dynels can be made more oriented, with stiffness comparable with that of Orlon at room temperature, but with no increase in crystallinity, and therefore the same low stiffness above the second-order transition temperature region. To correlate with crystallinity, the important temperature region for stiffness-temperature studies is above the second-order transition temperature region, and since the stiffnesses encountered there are generally low, a logarithmic representation is more informative. Dr. Eeg-Olofsson's charts, by their emphasis on the stiffness changes *below* the second order transition temperature and in the compression in values above this temperature, reflect the differences in mechanical treatment of the fibers not in crystallinity. Again the use of the term "stiffness" only, in my paper, without a detailed elaboration is, perhaps, unfortunate.

No particular brief was held in my paper for stiffness-temperature as a method for determining second-order transition temperature. Certainly the resiliency-temperature behavior yields an easier-to-see phenomenon, a minimum in a curve, than a change in slope phenomenon, as is seen in the curves depicting stiffness-temperature behavior. However, all methods for second-order transition temperature determination suffer with highly crystalline polymers, and I would predict that, for example, a density-temperature (dilatometer) curve for a highly crystalline nylon or Dacron would be as difficult to use as a stiffness-temperature curve for the determination of second-order transition temperature.

I acknowledge my error in language, and it is significant that our friends from across the water, with their precise approach to what is to them a foreign language, found it. However, the principles expressed in my paper are still valid, and need not be changed by the information in Dr. Eeg-Olofsson's letter.

ALEXANDER BROWN

INDUSTRIAL SECTION

The Judgment of Harshness of Fabrics[1]

Herman Bogaty, Norman R. S. Hollies, and Milton Harris

Harris Research Laboratories, Inc., Washington, D. C.

I. Introduction

The handle of cloth is utilized in many different ways as a measure of "quality" and commercial desirability. Along with cost and appearance, it is perhaps the only way consumers can assess the relative technical merit of a textile material. Throughout the course of manufacturing, from the selection of the fiber and its grading to the final chemical and mechanical finishing, a great many technical decisions are made on the basis of tactual judgments.

In view of its commercial and technical importance, it is not surprising that attempts have been made to evaluate hand instrumentally and objectively as, for example, in the classic work of Peirce [8]. More recently, with the advent of synthetics, efforts have been directed toward the understanding of fabric hand and related characteristics in terms of fiber properties [7, 9]. The basic difficulty suggested by the published work and by common experience is that handle is a complex of many properties which are integrated in the course of the subjective judgment. Thus, the A.S.T.M. has published [1] two proposed methods to assess only a few of the properties related to hand, as well as a table of eight descriptive terms of physical properties associated with it. Hoffman and Beste [7] discuss some 13 properties related to hand and Binns [3] has given a list of 28 different adjectives used by a group of observers in subjective descriptions of fabric hand.

None of the objective techniques has as yet been developed to the point where it is satisfactory to more than a very limited extent. It appears unlikely that the ability of the fingers to make sensitive and discriminating judgment and of the mind to integrate and express the result as a "single valued" judgment will be matched in the near future. In view of the widespread use of subjective evaluation of hand, the paucity of technical information on techniques and results is amazing. (In this connection the pioneering contributions of Binns [2, 3, 4] deserve more recognition and attention). This is in contrast with the considerable development in recent years of organoleptic testing in other industries (paint, food, beverage, packaging) where subjective judgments of sensory qualities of odor or flavor are now common and may even be used routinely for production control [6].

This paper describes some efforts to evaluate the subjective handle of fabric harshness in an organized and quantitative way. Some of the techniques, problems, and conclusions are thought to be applicable in other laboratories and mills. A means for classifying fabrics in a rigorous manner would appear to be a basic necessity for further development of more objective techniques. Some attempt is made to relate the handle of the fabrics studied to certain aspects of their construction—their fiber diameter and thickness.

In the work that follows, the term harshness is used to describe hand as a catchall word which seems to be most widely used and "understood" by the people involved in the test. The scale for this characteristic seems to run from harsh to soft (often "kind" in British usage), and one of its main components is the sensation of prickliness caused by contact of the surface fiber ends with the fingers. Other components appear to be stiffness and compactness.

II. Method of Evaluation

The test fabrics used in this study were a series of whipcord suitings made from wool, mohair, viscose, and nylon. Samples of these materials were

[1] This work was performed under Contract QM-564 which constitutes a part of the Army Quartermaster program of research on warmth, comfort, and other properties of blended fabrics.

supplied by the Home Economics Research Branch of the Agricultural Research Service, U. S. Department of Agriculture. The details of construction and very complete tests of the fabric are fully described by Morrison, *et al.* [10]; the same sample numbers are used herein to facilitate comparisons for those interested in test results of other properties. The test materials were considered especially suitable for the following reasons: (1) They were very similar in respect to usual construction features such as yarn size and twist, fabric texture and weight. (2) Finishing processes known to alter the handle markedly—fulling and napping—were not employed in their manufacture; also the fabrics were undyed, which eliminated a psychologically distracting factor. (3) The main variable in the fabric construction was fiber composition, which permitted an assessment of the role of blend and fiber type on handle.

The chief drawback of the fabrics was that as a group, they represented fabrics somewhat stiffer and harder than those generally encountered in usual experience with garment fabrics.

Binns [2, 4] has suggested that individuals of all kinds possess a native ability to rate the feel of fiber assemblies and of fabrics. His studies involved intercomparisons among groups of materials, the entire group being offered for rating at the same time, and their arrangement in a relative order of softness. This is the common practice in evaluation of handle today. A variation of this method involves the ranking of a series of fabrics relative to one fabric in the group specifically designated as a reference "standard." An experiment along these lines is described later (Experiment III) in which fabrics were offered in pairs for relative ranking by the observers; this method is referred to hereinafter as the relative or paired method.

An alternative approach suggested itself in which fabrics would be offered one at a time for judgment. Thus, if an innate ability for such judgments does exist in the observers, they should be able to express a judgment without immediate reference to a physically present material standard. While the use of such a "mental" standard was disturbing at first to some of the judges, it is clear that previous impressions and experience are the sole basis for a great many "absolute" subjective judgments made in daily life; no "standard" is usually present when a person judges a steak to have a fine flavor or a cashmere sweater to have a soft handle. The offering of one fabric at a time for judgment of harshness against a mental standard is referred to herein as the absolute or single-fabric method.

One basis for interest in the absolute method of judgment was the possibility of evaluation of large groups of samples with fewer observations than required by the relative method. Another important reason for attempting the single rather than relative judgments was based on unfortunate experiences with "nonlinear" arrays of fabrics. Thus, it is not unusual to find in evaluating three fabrics which do not differ too widely in harshness that A rates harsher than B, B is harsher than C, but C is harsher than A. This kind of result is a consequence of the multicomponent nature of the handle characteristic.

For the present study, 8×8-in. specimens of the fabrics were relaxed by wetting out in warm water for several hours, followed by suspension in air till dry. The samples were offered individually (or in pairs in a later experiment) to each of 12 people in the laboratory in turn. The group was equally divided into men and women and contained some observers with considerable experience in judging the hand of wool-type cloth as well as some with very little. The order of presentation was randomized with respect to judges and fabrics in each case. No observer was asked to make a judgment more frequently than once an hour to avoid any effects due to sensory fatigue.

III. Results of Harshness Judgments

A. Experiment I, Fabrics Offered One at a Time

Observers were asked "to judge with your eyes closed the handle of a sample of whipcord with respect to *harshness* or softness on a numerical scale as follows: 1—very soft, 2—soft, 3—moderately soft, 4—moderately harsh, 5—harsh, 6—very harsh. Please do not discuss this test with anyone." The average results for the fabric (mean for 12 observers) and for the judges (mean for 12 fabrics) are given in Table 1, columns 1A. The latter average, the mean of all the fabric scores recorded for each observer, measures the *observer* in terms of his tendency to rank the samples generally harsher or less harsh than another observer. Analysis of variance showed that both observers and fabrics contribute significantly to the total variability, i.e., fabrics differ significantly in handle and independently, the observers differ in the magnitude of their ratings. (When a result is discussed herein as being significant in a statistical sense, a confidence level of 95% or greater is implied.) For the mean

values shown, a difference of 0.6 units between any pair is required for significance to be asserted.

Thus, with this group of observers, differences among the fabrics can be assessed by the absolute method. There is an inbuilt scale which permits a quantitative judgment of a single fabric to be made, but this scale is somewhat different for different observers. That is, with the same external scale of values provided, some judges tended to use only the harsh end and others only the soft end of the range; some used a very restricted portion of the scale, while others spread their judgments over a wider portion of the assigned scale. Men tended to judge the harshness more severely on the average than women, but not significantly so; there was no consistent relationship between technical proficiency and level of judgment.

What is clear is that an average judgment may be made which can differentiate some of the fabrics. A single judgment by one observer, man or woman, expert or not, is of no value in discrimination by this technique. Errors in judgment, i.e., deviations from the mean, are made by all observers. For example, sample 2 is judged equal to or harsher than sample 6 by observers *C* and *H*; sample 9 is judged equal to or harsher than sample 17 by observers *L*, *M*, *B*, and *G*. Thus, averaging of the ratings of a number of observers, in addition to giving a more precise estimate of the sample through evening out the differences in scale, also evens out these momentary aberrations in judgment.

B. Experiment II, Fabrics Offered One at a Time

Since many of the observers did not use the full external range of classes of harshness provided, a second experiment was conducted with the same fabrics and observers, using fewer classes. Since, also, some of the judges were evidently using the harsh end of the scale, based on an assessment of the position of the test fabrics in the whole field of apparel fabrics in general, the question was reworded slightly to stress the desire for some limitation in the range of judgments visualized.

Observers were asked to judge ". . . the handle of a sample of whipcord with respect to harshness or softness, *for this type of fabric,* on a numerical scale as follows: 1—soft, 2—moderately soft, 3—moderately harsh, 4—harsh." The mean values are again given in Table I, columns II. To permit a comparison, the data of Experiment I were converted algebraically from a scale of 1–6 to a scale of 1–4, assuming linearity; these converted data are given in columns 1B, Table I.

Analysis of variance again showed the significant contributions of both observers and fabrics to the total variance. For the mean values shown (columns 1B and II), a difference of 0.4 units between any pair in a column is required for significance.

The change of scale and of emphasis in the question asked did not alter the main effects appreciably. The fabrics are judged in the same way and indeed the agreement in the two runs is remarkably good. There exist "harsh raters" and "soft raters" who seem to judge fabrics relatively in the same sense but differently on an absolute scale. In the same way, there are observers who use the full scale available and others who tend to use only one end.

The ability of the observers as a group to discriminate among the fabrics with respect to harshness by the absolute method is confirmed by the similarity in order of the samples and of the agreement of the numerical results in the two experiments. Every

TABLE I. Mean Values of Handle Judgments Grouped by Fabrics and by Observers

	Mean of fabrics				Mean of observers			
Sample No.*	1A	1B	II	III	Observer	1A	1B	II
1	2.7	2.0	1.8	—	A	3.9	2.8	2.8
9	3.3	2.4	2.4	2.1	B	4.1	2.9	3.3
7	4.0	2.8	2.7	—	C	4.1	2.9	3.3
2	3.8	2.7	2.8	2.4	D	4.8	3.3	2.9
10	4.0	2.8	2.8	2.4	E	3.8	2.7	2.6
16	4.1	2.9	3.1	2.5	F	2.8	2.1	2.5
14	4.4	3.1	3.3	—	G	4.4	3.1	3.8
8	4.3	3.0	3.4	—	H	4.9	3.4	3.5
17	4.5	3.1	3.3	2.6	J	4.3	3.0	3.1
5	4.8	3.3	3.3	—	K	3.6	2.6	2.8
15	4.4	3.1	3.6	—	L	5.0	3.4	3.3
6	4.7	3.2	3.8	3.1	M	3.3	2.4	2.3

* Numbered as in ref. [10].

observer commits some individual errors in judgment as before so that a single rating by one observer is again deemed to be of little value in classifying the fabrics.

C. The Judgment of Paired Samples, Experiment III

In order to compare the relative efficiency in making an absolute judgment of harshness of one fabric at a time versus that in making relative judgments on pairs, six of the fabrics covering the range were selected for test. These were samples numbered 9, 2, 10, 16, 17, and 6.

The six fabrics were given in pairs to the judges who were asked to judge "the relative rank of this pair of whipcords with respect to harshness" and to answer "(a) Which of the pair is harsher? (b) Is the difference: 0—negligible, 1—small but definite, 2—moderate, 3—large." All possible pairs were tested. By using positive and negative differences in the above ratings, algebraic sums and means could be obtained, as shown in Table II.

The general arrangement of the fabrics with respect to harshness is the same for the paired technique (as shown by the grand average values of Table II) as those given earlier for the single judgments in Table I. Indeed the grand averages shown in Table II were converted from a scale of -3 to $+3$ to a scale of 1 to 4; the results of this conversion given in column III of Table I are considered to be in good agreement with the earlier results.

Detailed examination of the data, furthermore, indicates that better discrimination is not afforded when pairs are judged. The comparative harshness of the samples determined directly (Experiment III) and by difference in the ratings (from mean of Experiments 1B and II) are shown in Table III. This tabulation is a means for determining whether any differences among fabrics are more readily assessed by one method (relative comparison) as against the other (judgment of one fabric at a time on an absolute scale). As arranged, the total scale for both columns of data is three scale units.

TABLE III. Difference in Harshness of Fabrics

Sample pair	Difference in harshness: A. Directly (from Expt. III)	B. By difference (from Expts. I & II)
2–9	0.7	0.3
2–10	0	−.1
6–2	.8†	.8†
6–9	1.6†	1.1†
6–10	1.3†	.7†
6–16	1.2†	.5†
6–17*	1.4†	.3
10–9*	.2	.4†
10–16	0	−.1
16–2	.4	.3
16–9	.8†	.5†
17–2*	.5	.5†
17–9	1.2†	.8†
17–10*	.2	.4†
17–16	.3	.2

* Comparisons which are judged differently by the two methods and are discussed in the text.
† Statistically different from zero.

The direct relative comparison is seen to result in differences of larger magnitude among the pairs of fabrics. However, in all but four cases (marked with an asterisk) the pairs are judged in the same way by the two techniques.

In only one case, pair 6–17, is a difference indicated by the results of Experiment III, where none is found in Experiments I and II; in three other comparisons (10–9, 17–2, and 17–10), no reliable difference is measured in the paired experiment, whereas a significant difference may be asserted by the results of tests of the fabrics judged one at a time. It is suggested that the paired judgments may in fact be more confusing to the observers because of the complex nature of fabric harshness. If the

TABLE II. Mean Judgments of Handle of Pairs of Fabrics

	Where X is sample: 9	10	2	16	17	6	Grand av.
9 is harsher than X by		−.17	−.67	−.83	−1.17	−1.58	− .88
10 is harsher than X by	.17		0	0	− .17	−1.33	− .27
2 is harsher than X by	.67	0		−.42	− .50	− .75	− .17
16 is harsher than X by	.83	0	.42		− .25	−1.17	− .03
17 is harsher than X by	1.17	.17	.50	.25		−1.42	+ .13
6 is harsher than X by	1.58	1.33	.75	1.17	1.42		+1.25

A minus sign indicates fabric is less harsh.
Statistical analysis indicates that a value in the body of the table of 0.8 must be reached on the average to be reliably greater than zero.

relative proportions of the component factors integrated by the observers into a single judgment of harshness are altered in going from pair to pair, then a difficult kind of decision is required of the judges. Thus, if a pair is presented in which one fabric is stiffer, more compact but smooth and nonprickly, and the other is compressible and lofty, but prickly on the surface, a conscious and uncomfortable decision must be reached by the observers.

This type of difficulty was clearly suggested for these fabrics by the comments of the judges. While the same factors operate in the absolute judgment of fabrics one at a time, the problem does not intrude as a conscious and distracting factor.

A tendency for momentary aberration in judgment was also noted in the paired series for all observers. Each judge made at least one "error" in his 15 ratings, and one observer made 4; an error was defined as the making of a judgment in the opposite sense from that given by the mean, where the latter was significantly different from zero. Where there was no significant difference in the pairs, an error was tallied where the observer noted a difference of an appreciable kind (at least two units different from the mean). The mean number of errors per judge was just under 2 per 15 observations.

It is concluded that, for these fabrics at least, the judgment of pairs or the inclusion of a standard for reference offers no clear advantage in ability to discriminate with respect to harshness. The judgment of one sample at a time by a panel of observers is at least as effective and offers economy with respect to the number of judgments that need to be made where the number of test items is large. On the other hand, with a trained panel, additional insight into the nature of the differences between a sample and a standard may possibly be obtained as a guide to research action. In either case, replication must be used, preferably by the use of a group of raters.

It will be recognized that the paired judgment technique is a special case of the common procedure in which a large group of samples may be offered for arrangement in relative rank. The main difficulties with this usual procedure are thought to be as follows:

1. The intrusion of other psychological cues which unavoidably affect the result. The classical result of this effect is illustrated by the probably apocryphal story of the test subject who selects the blue sweater as having the best handle of group, blue being her favorite color.

2. The onset of fatigue is well known when the array involves more than 4 or 5 items. The tendency to feel everything about the same and about in the middle of the group is a common experience for such judgments.

3. A judgment of one array cannot be readily related to another made at a different time without the inclusion of a sufficient number of control standards covering the range. The method of judging a single sample at a time at least offers the possibility for the existence of and rating on an absolute scale.

IV. Fabric Properties Related to Harshness

One of the important components of fabric harshness, especially in wool fabrics, is the resistance of surface hairs to bending. The prickle sensation given by short surface fibers acting as columns and resisting collapse by the fingers is also characteristic of some types of harshness [5]. Thus, from mechanical considerations it would be expected that harshness would be directly related to some function of fiber diameter and inversely to some function of the span length of the surface fibers. The relationship of fiber fineness to cloth softness is well known for animal fibers, particularly. Binns [4*c*] has shown that wool tops of various grades (i.e., fiber diameters) were readily distinguished through the sense of touch by trained or untrained people, including some who had never seen or handled top. The effects on handle caused by length of surface fibers are seen in fabrics which are made softer by a napping or brushing operation or conversely by shearing or close cropping. It was thought useful to briefly examine the subjective judgments of harshness obtained for these whipcords with reference to the fiber diameter and span length effects noted above.

In Table IV, the fabrics are grouped according to increasing fiber diameter together with their harshness ratings (mean results of Experiments I and II). The over-all effect of fiber diameter, with some interaction by effects due to length of surface fibers, is seen in the first three groups comprising fabrics made entirely of animal fibers or of wool blended with viscose. Increased harshness follows the use of coarse fiber, sometimes in spite of increased span length (group 2), sometimes concomitant with increased span length (group 3). In the last pair of fabrics of group 1, no alteration in harshness was observed with increasing mohair content, perhaps due to the counter-balancing effect of length of sur-

face fibers. Even with the nylon blends, the tendency is noted for the fabrics containing coarse wool to be judged harsher than those containing medium wool although the differences are not statistically significant. It is suggested that these fabrics were already at the harsh end of the scale by virtue of the span length effect. Thus all of the nylon blends are substantially thinner at low pressure than the other fabrics; since the compressed thicknesses of all the fabrics are identical, it is clear that the surface fibers of these nylon blends are of very short span length, consistent with visual observation. It is interesting that some members of the panel referred to these samples as hard, stiff, boardy, and papery, as well as harsh.

The effects of span length may be more clearly seen by rearranging the samples so as to compare the viscose blends with the nylon blends in fabrics containing the identical wool and synthetic content, i.e., samples 10 vs. 17, 9 vs. 16, 8 vs. 15, and 7 vs. 14. In every case the thinner fabric, i.e., containing fibers of shorter span length at the surface, was subjectively judged harsher.

V. Summary

Studies of the subjective evaluation of harshness, using a single type of fabric made from wool and blends with mohair, viscose, and nylon, are described. By means of a panel technique, fabrics may be discriminated with respect to harshness, and presumably similar techniques may be useful for other subjective properties. The evaluation of fabrics offered one at a time for judgment on an arbitrarily defined scale was found to be as efficient in discrimination as the more usual comparison with another fabric as a reference standard. A single judgment by a single observer is of little value in discerning differences in harshness; replication of the observations or of the observers is useful in smoothing out differences in judgment among observers or in minimizing a momentary error in judgment.

The harshness judgments are discussed in terms of certain structural characteristics of the fabrics tested. It is suggested that the subjective harshness is related to the diameter of the fibers used and inversely to the length of the fibers projecting from the cloth surface.

TABLE IV. Effect of Fiber Diameter on Fabric Harshness

Sample no.	Nominal fiber composition*		Harshness rating†	Low pressure thickness (0.002 p.s.i.)‖ (mils)
	Wool‡ (%)	Other§ (%)		
1	100 *F*	—	1.9	51
2	100 *M*	—	2.75	53
6	75 *M*	25 Mohair	3.5	56
5	50 *M*	50 Mohair	3.3	65
9	50 *M*	50 Viscose	2.4	58
7	50 *C*	50 Viscose	2.75	69
10	75 *M*	25 Viscose	2.8	82
8	75 *C*	25 Viscose	3.2	61
16	50 *M*	50 Nylon	3.0	39
14	50 *C*	50 Nylon	3.2	42
17	75 *M*	25 Nylon	3.2	42
15	75 *C*	25 Nylon	3.35	45

* As given in [10].

† Mean of cols. 1B and II, Table I.

‡ *F* = fine, 64's; *M* = medium, 56–58's; *C* = coarse, 48–50's [10].

§ Mohair was 28's grade, mean diameter 31 μ; viscose and nylon were 3 den. [10].

‖ All fabrics are 28 to 30 mils at 2.0 p.s.i.

Acknowledgments

The efforts of Mrs. Martha M. Kaessinger in conducting the panel tests are sincerely appreciated. A number of the ideas for judgment of subjective characteristics and methods for statistical evaluation which arose from discussions with Mr. E. B. Gasser are gratefully acknowledged.

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International Wool Textile Research Conference

Seminar

A seminar was held at the Hotel Biltmore, New York City, November 17, 1955, under the auspices of The Wool Bureau in conjunction with Textile Research Institute. At this meeting four speakers reviewed some of the more important findings disclosed at the International Wool Textile Research Conference held in Australia in the fall of 1955. These seminar papers, somewhat condensed, are given below. A complete list of the papers and lectures which were presented at the Australian Conference will be found in Appendixes A and B.

General Remarks on The Conference

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Introduction

The International Wool Textile Research Conference was an unusual and important event. Several of us Americans, who were privileged to attend this remarkable meeting in faraway Australia, believe that the Conference transactions were of considerable importance to the wool textile industry of the United States. Because the full Proceedings of the Conference will not be published until late in 1956, we felt obligated to bring to wool industry people of this country a condensed version of the more important findings reported.

This has been made possible by The Wool Bureau, with which Textile Research Institute is very happy to collaborate in the organization and presentation of this seminar. It is a pleasure also to acknowledge the cooperation of the Western Utilization Research Branch, U.S. Department of Agriculture, in permitting Dr. Harold Lundgren to make the long journey from California in order to contribute to the program.

In this introductory paper, an attempt will be made to give a very general picture of the Conference, its objectives and organization, and an appraisal of what was accomplished. Drs. Laxer, Lundgren, and Menkart will discuss the scientific papers. About 150 original scientific papers were presented at the Conference, each followed by comprehensive discussion. There were also 12 "invited lectures" and a number of symposia. Thus, it has not been easy to condense the proceedings into a three-hour presentation, and only the more important findings can be covered. Emphasis will be given to the practical implications. The various scientific phases of the Conference will be discussed as follows: Morphology and Chemical Modification, Gerald Laxer, Director of Science and Technology, The Wool Bureau, Inc.; Physical and Protein Chemistry, Harold P. Lundgren, Head, Protein Section, Western Utilization Research Branch, U. S. Department of Agriculture; Biology and Manufacture, John Menkart, Assistant Director of Research, Textile Research Institute.

Purpose of the Conference

The International Wool Textile Research Conference was held in Australia under the auspices of the Commonwealth Scientific and Industrial Research Organization, the Australian Wool Bureau, and the Commonwealth Wool Adviser for the purpose of a general stocktaking of scientific progress relating to wool. The appropriateness of Australia as the scene for this meeting lies in the importance of that country in world wool production and the extensive research effort which is being carried out on the various phases of the wool problem. The Conference was originally suggested by the Commonwealth Scientific and Industrial Research Organization, here-

[1] Director, Textile Research Institute.

inafter referred to as CSIRO. The suggestion was adopted enthusiastically by the Australian Wool Bureau, which represents the wool growers of Australia, and the Commonwealth Wool Adviser.

The CSIRO is the central government research organization of Australia, which is charged with carrying out both basic and applied research on the products and industries of that country. The organization comprises sixteen major establishments or divisions, which are further divided into sections. In 1954 CSIRO spent $8,600,000 from Commonwealth treasury funds, plus another $2,250,000 derived from sources such as the various field stations. Contributions from industry amounted to about $56,000. The CSIRO covers a wide variety of topics, such as animal nutrition, building, entomology, forest products, food preservation, radiophysics, ore-dressing, wool and textiles, etc. It is understood that about a third of the research effort of the CSIRO is concerned with wool. The total personnel of CSIRO is approximately 2,000, of which about 1,000 are professionals.

The CSIRO operates a number of laboratories. Among those visited by the Conference delegates were: Physics and Engineering Unit, CSIRO Wool Textile Research Laboratories, Sydney; CSIRO Sheep Biology Laboratory, Prospect; Applied Research Unit, CSIRO Wool Textile Research Laboratories, Geelong; Biochemistry Unit, CSIRO Wool Textile Research Laboratories, Melbourne.

The delegates were very favorably impressed with the equipment, staff, and program of each of these laboratories.

The Delegates

There were 100 official delegates to the Conference, 53 of whom came from overseas. The following breakdown by countries, and rough division by principal fields of interest, indicates the scope of the meeting:

Country	Delegates
Australia	48
Canada	2
France	2
Germany	2
India	1
Japan	2
New Zealand	4
South Africa	2
Sweden	1
United Kingdom	25
United States	11

Field	Delegates
Biochemistry	18
Biology and wool metrology	17
Engineering and mathematics	4
Organic chemistry	11
Physics and biophysics	16
Physical chemistry	15
Textile chemistry and technology	19

Arrangements and Organization of Meetings

The Conference was an exceedingly ambitious undertaking, since it involved the development of a scientific program of sufficiently high caliber to bring together such a large group of scientists of widely varying interests from eleven countries. The meeting was held under the chairmanship of Dr. F. W. G. White, C.B.E., Chief Executive Officer of CSIRO. All of the facets of organization and execution of the Conference were handled ably by various staff members of CSIRO, many of whom were scientists. Provisions were made for every contingency, and no possible requirement of an overseas delegate was overlooked. The cost of the meeting to CSIRO has been estimated at about £A50,000 ($110,000), a considerable portion of which was expended in supplying travel funds to academic people from abroad. It is estimated that publication of the proceedings of the meeting will require five volumes and involve an expenditure of about £A15,000 ($34,000).

The Conference proceedings occupied a total period of three weeks and took place successively in Sydney, Geelong, and Melbourne. Between the Sydney and Geelong meetings, delegates were given tours of wool-growing regions of Southeast Australia. The strictly scientific meetings were held in the three Wool Textile Laboratories of the CSIRO —the Physics and Engineering Unit in Sydney (Officer-in-Charge, V. D. Burgmann, B.Sc., B.E.), the Applied Research Unit in Geelong (Officer-in-Charge, M. Lipson, B.Sc., Ph.D., F.T.I.), and the Biochemistry Unit in Melbourne (Senior Officer-in-Charge, F. G. Lennox, D.Sc.). These arrangements provided opportunities for inspection of the laboratories, each of which was provided with a specially decorated auditorium, furnished with comfortable theater-type seats and equipped with excellent projection and public-address systems. At the close of the Sydney and Geelong meetings, the seating and other equipment were packed into trucks and moved on to the next meeting place. These mechanical arrangements were carried out with amazing smoothness and, as far as could be learned, without a single misfire. At each laboratory there was a comfortable lounge and writing room for the delegates, alphabetically labeled mail boxes were provided, and CSIRO had offices set aside to handle local and overseas transportation. Representatives from the Commonwealth Bank were also present to handle financial problems. Hotel arrangements had been

made in advance in the various cities, and buses or cars operated on a regular schedule to take the delegates back and forth from the laboratories where the meetings were held and to the meetings held in various other locations, such as the University of Sydney and the University of Melbourne.

Official and unofficial hospitality was copious during the period of the Conference. In addition to the dinners and receptions given for the delegates by government officials and by the Australian Wool Bureau, there were a number of other affairs which served the important function of getting the delegates acquainted. For example, delegates were entertained at the homes of V. D. Burgmann, Director of the CSIRO Laboratory in Sydney; M. Lipson, Director of the CSIRO Laboratory in Geelong; F. G. Lennox, Director of the CSIRO Laboratory in Melbourne; and Professor P. R. McMahon, Head of the School of Wool Technology of East Sydney Technical College. Professor McMahon also took a group of delegates for a sail aboard his yacht on Sydney Harbor. Buffet dinners were served by the Woollen and Worsted Manufacturers Associations of New South Wales and Victoria at the University of Sydney's Union House and the Gordon Institute of Technology in Geelong, respectively.

All contributed scientific papers were given according to the British system, i.e., preprints in the form of galley proof were supplied prior to the meetings, and the author was allowed five minutes for presentation, with a following discussion period of ten to fifteen minutes. This system worked surprisingly well considering the unusually severe time limitations. Almost all of the authors held to the five-minute schedule and managed to give sufficient background to permit discussion on the part of those who had not read the preprints as well as those who had read them. The discussions were animated, and in almost every case, had to be terminated by the session chairman in order to permit adherence to the schedule. In addition to the contributed papers, there were "invited lectures" of about an hour in length—some specialist in nature and some more general in character, the latter being open to the public. The whole program is given in Appendixes A and B.

Tours of Wool-Growing Areas

The purpose of the tours was to give the participants in the Conference a view of the principal types of sheep-growing country in Australia, to enable them to meet some of the people concerned with sheep raising, and to demonstrate the advances in the industry brought about by pasture improvement, irrigation, soil conservation schemes, and the elimination of the rabbit pest by myxomatosis. The whole cost of the tour from Sydney to Geelong was borne by the CSIRO.

The trip started with a flight from Sydney to Canberra, the Commonwealth Capitol, early on Friday, August 26. That day was spent in Canberra.

The tour proper began the following morning, Saturday, August 27. The party was divided into two sections. Coaches were used for transportation, and each group was accompanied by a guide, a local agricultural extension officer, who gave a running commentary and answered questions on the geology, climate, and agriculture of the district.

The two tours occupied four days and covered distances of 700 and 1,000 miles, respectively, through the highly varied sheep-growing country of New South Wales, Victoria, and South Australia. Prearranged stops were made at various sheep stations, studs and shearing sheds. The tremendous advances made in developing new pastures, improving breeds, and ridding the country of pests were clearly evident. On Tour II, only two rabbits were seen, indicating the effectiveness of the virus disease, myxomatosis, which was introduced by CSIRO. Information gained by the delegates during the tours was exceedingly valuable, for they were forcibly brought to understand the great problems still facing the Australian scientist as well as those which he has already met so effectively.

Recapitulation and Appraisal

Fortunately, the CSIRO will publish the complete proceedings of the meetings, which will include all papers and the discussions in full. But it will be a year or longer before the proceedings will be available, and they will occupy several large volumes. Thus, at this time, it seems worth while to attempt to answer the questions: (*1*) what was accomplished by the Conference, and (*2*) what are the inferences for the future of wool?

Just what was accomplished? Any scientific meeting is likely to be a "good thing," of course, since it brings scientists together and permits interchange of ideas and analyses of their findings. But the International Wool Textile Research Conference was un-

usual in several respects. First of all, every paper presented was in some way related to a single basic raw material, wool, rather than to some branch of science such as organic chemistry, electrical engineering, or nuclear physics, as is usually the case. Second, the meeting was endorsed not only by the research people of CSIRO but by the representatives of the Australian wool growers, the Australian Wool Bureau, and by the government of that great wool-producing country. Third, the meeting was truly international in character with scientists of eleven countries participating. Fourth, the scientists participating in the Conference represented many divergent disciplines: biologists, protein chemists, electron microscopists, physical chemists, chemical physicists, entomologists, textile engineers, etc. Fifth, and perhaps most surprising, most of these scientists of widely different persuasions appeared to be interested in all the fields encompassed by the Conference; frequently, one found academic "purists" sitting in on sessions devoted to the practical aspects of wool processing, while a number of the "applied" physicists and engineers followed closely the more abstract papers on protein chemistry.

Suppose now we presume to list what seem to be the major accomplishments of the Conference:

1. The interest of a considerable number of capable scientists with widely varying disciplines and fields of research was brought to focus on the problems of the wool producer.
2. The scientists of CSIRO and other Australian research institutions were given an opportunity to appraise their programs and findings against a background of international scientific thinking and differing concepts of wool technology.
3. Overseas scientists were given the opportunity to study at first hand the real problems of the wool producer and of the biologist who is seeking to guide the producer. Resulting information, difficult to gain by reading or occasional conversations, will be invaluable in guiding wool research programs in wool-consuming countries such as the United States.
4. A survey of the scientific papers presented indicates that much progress has been made in achieving a better understanding of the structure of wool keratin, the morphology of the wool fiber, and its physical behavior, but it is clear that these problems are far from complete solution.
5. Great advances appear to have been made by biological research which should permit development by breeding of almost any type of wool desired, but there is a great void in our information as to what types of wool are desirable from the standpoint of processing and fabric quality.
6. Some promising developments in wool processes, particularly scouring, were reported, but these must be further evaluated against a background of the most modern and efficient existing processes.
7. Several chemical treatments to improve the properties of wool, such as resistance to felting, shrinkage, moths, etc., were described. The Conference was marked by objectivity in approach to the desirable properties of wool as well as its weaknesses in relation to other fibers.

The fact that Australians recognize the need for intensified scientific effort to preserve the position of wool in the international fiber economy by setting up extensive fundamental and applied research programs in Australia and abroad and by organizing this International Wool Textile Research Conference, is significant and should be noted carefully by wool growers of other countries. It is high time, however, that a move be made in this direction, for wool is still bought and sold purely on the basis of subjective qualities which often have little direct relation to the needs of the wool manufacturer. In contrast, the newer synthetic fibers are furnished to the manufacturer with complete quantitative data on their properties and specifications for their processing and end-product application. It will be a most difficult task to put wool on a comparable "quantitative specification basis," but it appears that there is a growing realization in Australia that this must be done if wool is to survive as an important raw material of the textile industry.

It is not to be inferred from the preceding discussion that scientific research can do the whole job for wool. Sound marketing studies and effective promotion must accompany the work of the scientist. The signal advances scored for cotton in the United States through an intelligent coupling of these functions should be encouraging to the wool grower, but he must be brought to realize that his problem is much more difficult because of the basically higher price of the wool fiber and the international aspects of its processing and consumer use. Fortunately, wool is a very good fiber with unique properties, and there may yet be time for a sound program of scientific research to have its effect. In any event, the International Wool Textile Research Conference seems to have been a step in the right direction.

Morphology and Chemical Modification

Gerald Laxer

The Wool Bureau, Inc., New York, N. Y.

Morphology

The complex structure of the wool fiber is not restricted to the architecture of the protein molecules of which it is composed, rather complexity is found at all levels of organization up through the cellular constituents themselves and their arrangement in the fiber. This latter situation has always incited some morphological and histochemical investigations on the cells of the wool fiber, but with the development of new tools and techniques for exploration, and with the recent discovery of the bilateral asymmetric structure of a *highly* crimped, nonmedullated wool fiber, such studies have been amplified considerably in recent years. Moreover, the follicle which produces the wool fiber has received much attention as well, since fundamental secrets of animal fiber formation rest in this living structure. There is no doubt that the results of these investigations are contributing to a better understanding of the behavior of wool fibers in processing as well as to the exceptional performance characteristics of wool articles, and some of these studies which were reported at the Conference are summarized below.

The Fine Structure of Cortical and Scale Cells

The nonmedullated wool fiber consists of two types of cells. The main body, or cortex, which accounts for over 90% of its weight, is made up of cigar-shaped cells which are cemented together. The outside cellular portion is composed of a single layer of flat, scalelike cells which overlap somewhat like shingles on a roof. Covering this outer layer of cells is a very thin, nonproteinous, semipermeable membrane or sheath known as the epicuticle.

Cortical cells. Electron microscopic studies on cortical cells were reported which are helping to close the gap in knowledge between the histological and molecular levels. For instance, Jeffrey, Sikorski, and Woods examined highly degraded cell fragments from a number of keratin fibers which were not opaque to the beam of the electron microscope. They found that breakdown usually proceeds by stages, the first being the separation of the keratin of cortical cells into thin sheets or ribbons of fibrillar material. Next the sheets break down into individual fine threads called "microfibrils" (100–300 A in diameter; 1 A = 0.004 millionths of an inch). When the disintegrative treatment, e.g., oxidation or reduction which modify disulphide cross links, is severe enough, the microfibrils show a nodular or globular fine structure; sometimes the microfibrils disintegrate into individual globular units. In another paper Mercer, Farrant, and Rees reported observations on ultrathin sections of follicles taken below and above the level of keratinization. They traced the formation of the apparently homogeneous masses of keratin which characterize the fully hardened cell and support the view that the fibrous keratin consists of longitudinally aligned microfibrils (100–300 A) which are nodulated, and that these microfibrils are the primary fibrous units. Since the microfibrils appear nodulated, Mercer, *et al.*, suggest that they are formed in the presumptive cortical cell by the association of protein globules.

Jeffrey, *et al.*, and Mercer, *et al.*, agree that in addition to the fibrous microfibrils or sheets of microfibrils, the cortical cell contains an amorphous "cementing" protein which is rich in cystine residues. As a result of their studies, Jeffrey, *et al.*, concluded that there is a difference in the reactivity of disulphide cross links at different histological levels in the fiber. A further point which deserves mention here is that Jeffrey, *et al.*, found that cortical cells of Lincoln wool and merino wool break down in different ways as far as their histological structure is concerned when they are subjected to similar disintegrative treatments. This is somewhat in line with other work reported at the Conference by Dusenbury and Menkart, and Fraser and Rogers, which deals with the marked differences in the chemical reactivity and structure of the cortex of various types of animal fibers (see below).

Scale cells. A new method for examining the fine structure of the surface of wool fibers was described in a paper by Ramanathan, Sikorski, and Woods. These workers developed new surface replication techniques, and specimens were examined with the electron microscope; interpretation was facilitated by

using stereoscopic methods. Using Lincoln wool, it was found that the individual scale cells are often bordered by striated bands. In general, each scale cell tends to be broadly corrugated toward the root-end, while the whole surface is often traversed by a system of fine longitudinal striations (Figure 1). The epicuticle is often torn at the scale edges.

The keratin protein of scale cells is reported not to possess a fibrous or fibrillar texture in the paper by Mercer, *et al.*, but Fraser and Rogers, who examined metal-shadowed fiber fragments with the optical microscope, reported that the inner surface of the cuticular sheath is extensively pitted and shows evidence of a fibrillar structure. Fraser and Rogers also state that the main bulk of the scale cell, the endocuticle, is involved in some way in the fusion of the scales to form a cuticle. Possible mechanisms of this involvement were considered in some detail by Fraser and Rogers, as well as alternative explanations for the continuity of the cuticle. The histological nature of the very resistant semipermeable outermost membrane, i.e., the epicuticle, which confers water-repellent and other desirable properties to the wool fiber, is also considered in some detail by Jeffrey, *et al.*, Mercer, *et al.*, and Fraser and Rogers.

The identification of various types of animal fibers by their scale pattern under the optical microscope was discussed quite thoroughly in a paper by Wildman. The preparation of subsamples for examination, techniques for preparing casts and impressions, and a new classification for scale patterns (as well as medullae) were given in Wildman's paper.

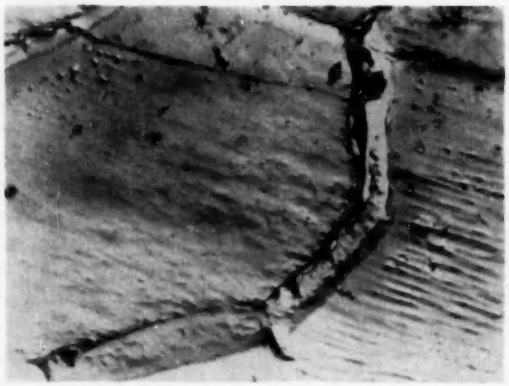


Fig. 1. Electron micrograph of a two-step (silver-silicon dioxide) replica of the surface of a Lincoln wool fiber. ("The Surface Structure of Wool Fibres," Ramanathan, N., Sikorski, J., and Woods, H. J., Appendix A.)

Histology of Animal Follicles

Development. The development of the various types of follicles in the merino foetus was described in considerable detail in a paper by Hardy and Lyne. Eight fundamental stages in the development of mammalian hair follicles were found, and these are shown for both primary and secondary follicles in Figures 2 and 3.

Primary follicles, which start to develop about the 50th day of intra-uterine life, possess a wax (sebaceous) gland which produces wool grease, a sweat (suint or sudoriferous) gland, and a muscle (*arrector pili*). *Original* secondary follicle development is initiated after the 85th day of intra-uterine life; these follicles do not have a muscle nor do they possess a sweat gland, and they may or may not have a wax gland. Hardy and Lyne showed that the majority of secondary follicles do not arise directly from the skin, but as branches from the original secondary follicles (Figure 3). By the beginning of the post-natal period, branching is extensive and original follicles may be associated with one to eight ***derived*** follicles. The wool fibers produced by a family of secondary follicles emerge through the common opening in the skin, and the fiber produced by the original secondary follicle tends to be thicker and is more frequently medullated than those produced by derived follicles. The branching phenomenon exhibited by original secondary follicles explains the fact that there are more fibers from secondary follicles in the fleece of the mature wool-producing sheep, although the ratio of secondary to primary follicles varies considerably with the breed. In merinos, the sheep producing coarser wools have S/P ratios around 17 or 18 to 1, and the fine- and medium-wooled sheep about 22 to 1. The very high S/P ratio of fine- and medium-wooled merinos probably accounts for the more uniform nature of wools produced by these sheep. It is worthwhile to mention here that Speakman and co-workers have shown that there are marked differences in the chemical and physical properties between wool fibers from the primary and secondary follicles, and Speakman suggests that such variations between wool types of approximately the same fineness probably account for "character" differences noted by the practical man.

Growing wool fibers in vitro and the blood supply to the follicle. A technique for growing wool on small sections of foetal skin after it is dissected from the animal was described in another paper by Hardy

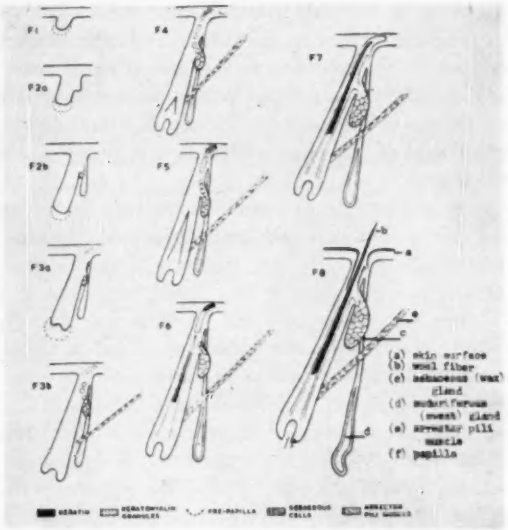


Fig. 2. Diagram of stages F1 to F8 in development of original secondary wool follicles in the merino foetus. Some stages in development of *derived* secondary follicles are also shown. ("Development of Wool in Merino Foetus," Hardy, Margaret H., and Lyne, A. G., Appendix A.)

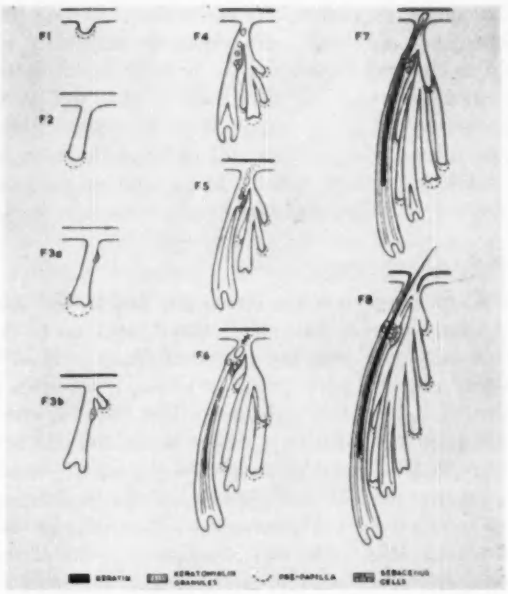


Fig. 3. Diagram of stages F1 to F8 in development of primary wool follicles in the merino foetus. ("Development of Wool in Merino Foetus," Hardy, Margaret H., and Lyne, A. G., Appendix A.)

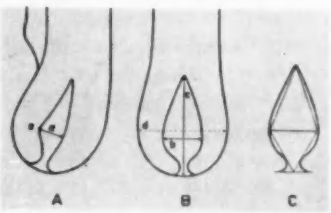


Fig. 4. General form of papilla and follicle. ("Size and Shape of Papilla in Wool Follicles," Rudall, K. M., Appendix A.)

and Lyne. With refinement of this technique, Hardy and Lyne state that it should be possible to study directly the effects of certain mechanical, nutritional and hormonal factors on the initiation and development of wool follicles.

The immediate supply of blood to wool follicles was reported in a paper by Ryder. The follicle bulb is apparently surrounded by a network of capillaries which supply nutritive substances; blood vessels in the papilla are usually connected with the surrounding network of blood vessels. It is interesting that follicles develop in the foetus without any special blood supply, but follicle blood networks appear when the fibers are about to erupt through the skin. It is not clear whether there is any relationship between the spacial arrangement of blood vessel network around the follicle and the amount and type of crimp of the fiber produced.

Papilla in wool follicles. The size and shape of the papilla in various types of wool follicles was described in a paper by Rudall. He showed that the rate of growth of wool fibers corresponds to the ratio of the papilla volume to the papilla surface area. From other observations, Rudall states that the papilla itself determines the shape of the fiber produced. For instance, crimp formation seems to be dependent on the presence of an asymmetrically-shaped papilla in the follicle (Figure 4, A). The asymmetrical papilla is oriented in a special way relative to the follicle and the crimped fiber; the minor diameter of the papilla being parallel to the minor diameter of the formed fiber.

The relationship between the cross-sectional shape of the papilla in hair and wool follicles and the cross-sectional shape of animal hairs varies, and it is pointed out by Rudall that the cross-sectional shape of the papilla more or less determines the cross-sectional shape of the fiber.

It can be seen from this brief review that the type of follicle and the nature of the various structural elements of the follicle markedly influence the characteristics of the fleece. Further research to gain a fuller understanding of the level of influence of the

various follicle factors is required, but it is clear that when this knowledge is obtained, the possibility remains that the factors can be brought under better control genetically or otherwise so that the wool-grower will be able to supply wools of specified characteristics. The problem still remains, however, to establish objectively which characteristics of the wool fiber are important and what are their desirable levels.

Ortho– Paracortex

About three years ago Horio and Kondo, and subsequently Mercer and others, called attention to the interesting fact that the cortex or main body of a highly crimped fiber (such as merino) possesses a bilateral asymmetric structure. The elliptical cross section of such a fiber appears to be divided into two approximately equal portions by a jagged line which is roughly parallel to the major axis of the ellipse; the line may well be the boundary between two groups of cortical cells. The two components of the cortex differ from each other in their chemical and physical properties. For instance, the portion which was designated as the "orthocortex" shows a greater dye receptivity, greater swelling in alkali, and greater loss in birefringence after exposure to alkali than the other section, which is called the "paracortex." (The "ortho–" and "paracortex" terminology was officially approved by the Conference.) Along the axis of the fiber the line which separates the two cortical sections rotates so that the two sections are in the form of hemicylinders wound around each other helically in phase with the fiber crimp. In relaxed fibers the orthocortex is placed at the outside portion of the crimp bend, while the paracortex forms the inner portion (Figure 5). These observations suggest that the crimp of the wool fiber is intimately associated with the cellular components of the cortex and thus is not superimposed on the fiber from the outside. Since one half of a highly crimped wool fiber will respond more readily than the other to changes in humidity in the atmosphere, the fiber's behavior with humidity fluctuations is probably somewhat analogous to that of a bimetallic strip with temperature changes. Thus, distorted fibers in fabrics are aided by their asymmetric reaction with water vapor in taking up their original crimped form so that bulkiness and shape are restored.

An excellent review of the ortho– and para– phenomenon was presented in a paper by Dusenbury and Menkart. They discussed such factors as: (*1*) the cause of the phenomenon in terms of the fiber-forming mechanism in the follicle; (*2*) the relationship of the phenomenon to the formation of crimp; (*3*) the differences between the ortho– and paracortex molecularly and morphologically; and (*4*) the appearance of the phenomenon over a range of animal fibers.

It is worthwhile to mention here that Dusenbury and Menkart mentioned that Dusenbury and Coe showed unequivocally that, contrary to earlier belief, the orthocortex absorbs both basic and acid dyes (Figure 6). Dusenbury and Menkart note that this throws doubt on some earlier chemical analytical work on the amino acid compositions of the ortho– and paracortex and suggests that the differential dyeing in the orthocortex with both types of dyes may be due to an excess in the orthocortex of dyeing sites of both the acid and basic type, if the phenomenon is an equilibrium one. It is pointed out that alternatively the difference may be due to differences in the state of organization of the two portions (possibly accompanied by different cystine contents) without any major variations in composition.

A further difference in the chemical properties of the two cortical sections of one type of fiber is mentioned by Dusenbury and Menkart, who pointed out that Dusenbury, *et al.*, showed that the orthocortex of a 64's Rambouillet wool is probably sensitized by acid at a rate eleven times greater than the paracortex. In another paper on this subject, Fraser and Rogers showed by a metal shadowing technique that on treatment with alkaline thioglycollate solutions, the ortho-cortical cells of merino wool break down

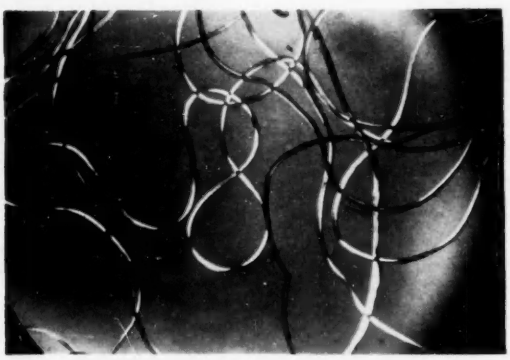


Fig. 5. Dyed crimpy wool fibers showing the hemicylinders of orthocortex-paracortex helically twisted around each other in phase with the fiber crimp. (Courtesy of Textile Research Institute.)

more readily into keratin fibrils than the corresponding para-cortical cells.

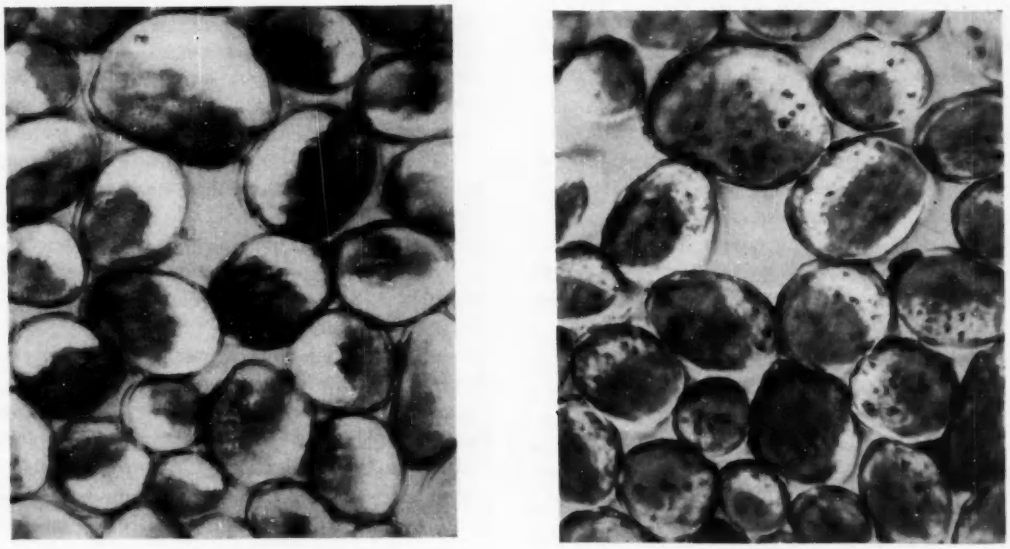
Differences between Fiber Types

Significantly, Dusenbury and Menkart point out that ample evidence exists which indicates that some bilateral differentiation in the cortex occurs over a whole range of keratin fibers. Reference was made to the work of Dusenbury and Jeffries. These workers used dyeing techniques, alkali solubility measurements after various times of exposure to sulfuric acid and allied studies, to show that human hair is a "pure para" fiber with no structural asymmetry; mohair is a "pure ortho" fiber; Rambouillet wool possesses a bilateral structure; and B.A. fleece wool has a two-component cortex, but does not possess a bilateral structure of the type present in fine wool fibers. It seems likely that the B.A. fibers have a radially differentiated cortex, as described for coarse Lincoln wool by Frazer and Rogers (the para-segment forming an annulus around an ortho core). Fraser and Rogers also note that bilateral asymmetry in a number of wool types becomes less well-defined with increasing wool fiber diameter, and there is gradual transition from bilateral asymmetry to radial differentiation in going from fibers 25 μ thick to those 40 μ thick; the latter phenomenon can be correlated with change in follicle structure.

The Follicle and Bilateral Structure

That ortho– and paracortical cells are formed in the germinal layers or bulb of the follicle and are not differentiated later as a result of uneven keratinization, as claimed earlier, was shown also in a second paper by Fraser and Rogers. Their histochemical experiments showed that differentiation of each type of cortical cell is associated with asymmetry in the structure of the follicle itself. Rudall (see above) found that an asymmetrically-shaped papilla is associated with fibers producing crimpy fibers. The origin of these two types of cells in the germinal layers of the follicle was also suggested in a paper by Laxer and Whewell, who showed that in follicles producing pigmented crimpy fibers, the pigment producing cells, which are only active in the germinal layers, are asymmetrically distributed in this region. Laxer and Whewell note that such follicles produce fibers containing pigment granules which are distributed in a bilateral asymmetric manner, and that the paracortex of such fibers contain the greater amount of pigment granules.

With these important discoveries, reported at the Conference, of the different chemical and physical



(*a*) (*b*)

Fig. 6. Successive cross sections of crimpy wool fibers dyed with a basic dye (*a*) and an acid dye (*b*), illustrating that the orthocortex absorbs both types of dyes. (Courtesy of J. H. Dusenbury and A. B. Coe, Textile Research Journal, April, 1955).

characteristics of fibers possessing different amounts of the two cortical fractions, the widespread variations in behavior which exist between wool types have come into even sharper focus. The picture, however, is becoming an orderly one because an over-all pattern is emerging. On the other hand, much work remains to be done to establish quantitatively the effects of chemical treatments, particularly those used in processing, on the fiber properties of a wide range of wool types before the maximum advantage can be obtained from such information at the practical level.

Chemical Modification of Wool

Wool can be chemically altered with relative ease because there are a large number of reactive sites in its protein substance, and these are readily available to modifying chemicals. The relatively high chemical reactivity of wool is undesirable in some instances, for in its unmodified state it can be degraded by biological and chemical agents with which it comes into contact in the course of processing and use. On the other hand, the sites in the protein which are prone to attack can be stabilized by chemical modification, because of their relatively high chemical activity. Thus, wool can be made highly impervious to biological and chemical attack and, in addition, other new and desirable properties can be imparted to it by chemical treatments. For instance, wool can be altered so that it becomes resistant to felting shrinkage, more resistant to extension and permanently set in a strained condition, etc.

A large number of papers were presented at the Conference which described new techniques and chemical reagents for modifying both the surface and internal structure of the fiber in order to obtain specific effects. Although these chemical treatments are only laboratory or pilot plant processes at this point, they are pointing the way to the large-scale production of wool with new and desirable properties which will facilitate its manufacture and enhance its usefulness in end products.

Surface Modification

The surface modifying effects of acid, alkaline, oxidizing, and reducing agents in organic solvents; of enzymes; and of pure solvents were described in a paper by Wikström, *et al.* It was found that the surface reactivity of the fiber, as measured by the change in wettability, could be increased by such reagents, especially hydroxyl ions in organic solvents. Wikström, *et al.*, claim that results are consistent with the idea that the treatments make the surface layer more polar in character, *viz.*, the surface has a greater affinity for water. The attack, however, is not confined to the mathematical surface, but it is never great enough so that the internal structure of the fiber is modified. The authors state that under the conditions of treatment, it is the cystine cross links of the cuticle which appear to be the modified group. It is clear from this work that by increasing the wettability of the wool fiber, through the use of the proper surface-modifying reagents, the wet processes to which wool is subjected, such as dyeing, bleaching, etc., can be made more rapid.

Shrink-resistant wools can be produced by modification of the fiber surface, and those papers presented at the Conference dealing with effects on felting shrinkage of surface deposits of resin are described on p. 379.

Stabilization by Internal Modification

Cystine-lanthionine transformation. It is well known that when wool is treated with alkali under the proper conditions, the disulfide cross links ($—CH_2—S—S—CH_2—$) between the polypeptide chains are converted into lanthionine cross links ($—CH_2—S—CH_2—$), and that the latter are more stable to attack than the natural disulfide type. The mechanism by which cystine is converted into lanthionine has been obscure.

Schöberl and Wagner presented a paper in which they showed that cystine can be converted directly into lanthionine, and that other amino acids, particularly those adjacent or near cystine in the protein, are not necessary for the formation of the thioether cross link. The authors claim that the reaction probably involves the splitting of the disulfide cross link by hydrolysis with formation of a mercaptan and a dehydroalanine residue (α-amino acrylic acid) as intermediates with elimination of hydrogen sulfide and elementary sulfur.

Since wool undergoes a number of alkaline treatments in the course of processing, the cystine-lanthionine conversion is an important one to the technologist. Furthermore, it is the disulfide cross link of wool which is attacked by the digestive juices of the moth grub, and this conversion may be important in producing moth-resistant wools. With these practical implications in mind, it is worthwhile to mention the paper presented by Zahn and Osterloh, wherein they describe a new method for the practical conversion of cystine in wool into lanthionine. The process in-

volves treatment of wool with organic solvents such as dioxane, propanol, or ethanol in combination with an alkali solution such as borax or sodium carbonate at 65° C. It is noteworthy that these alkalies do not produce significant amounts of lanthionine when they are used apart from the organic solvents. The authors point out that in practical processing, the concentration of organic solvents should not exceed the point where the alkali, which would be harmless in itself, can attack the wool protein.

A method for determining lanthionine and cystine in amino acid mixtures which involves chromatographic separation on ion-exchange columns, followed by a ninhydrin colorimetric estimation, was described in a paper by Blackburn and Lee. These workers showed that in alkali-treated wool, one molecule of lanthionine is formed for every molecule of cystine lost. Cysteine, formed by the reduction of cystine, can be estimated by a new method described in a paper by Zuber, Traumann, and Zahn. It was shown that when wool is treated with fluoro-2,4-dinitrobenzene at pH 5, 60° C., s-dinitrophenylycysteine can be separated from a subsequent hydrolysate by paper electrophoresis. The isolated compound can be estimated colorimetrically, and the method allows the determination of minute amounts of cysteine.

Formalization of Wool

Cystine-lanthionine transformation. Oku and Shimizu reported that the alkali solubility, dissolution velocity in 15% potassium hydroxide, resistance to felting shrinkage, and elastic recovery of wool are improved considerably by treatment of wool with active formaldehyde liberated from acidic solutions of hexamethylenetetramine (HMTA). It was noted that the best conditions for the formalization are treatment of wool for 45 min. at 90° C. with a 0.6 to 1.0% aqueous solution of HMTA acidified with acetic acid in 150% excess over the theoretical amount (wool to solution ratio: 1 to 100).

The mechanism of the reaction of formaldehyde with wool was discussed in a paper by Richards and Speakman. These workers do not agree with the earlier conclusions of Alexander, *et al.*, that when wool is treated with formaldehyde at 60° C., pH 6 to 7, cross links are formed between the phenyl groups of tyrosine residues and the amino groups of lysine residues.

Action of Ninhydrin on Wool

Cystine-lanthionine transformation. Speakman and Cockburn presented two papers dealing with the reaction between wool and ninhydrin (1,2,3-indantrione hydrate). They reported that after wool is treated with an aqueous solution of ninhydrin, the fibers are much more resistant to extension in water. It was found that the rate of reaction increases with increasing temperature; a boiling solution of ninhydrin (1%) gives maximum strengthening at pH values between 4 and 7. Speakman and Cockburn suggest that the basic side chains of lysine and arginine residues play a fundamental part in the reaction, but that the extremely high degree of strengthening is probably not due to cross linking since model experiments showed that ninhydrin is a monofunctional compound. It is noted that wool develops a purple color on strengthening and that the nature of the color complexes is unknown, so that a complete explanation for the strengthening action of ninhydrin is still lacking.

Reduced wool fibers, i.e., those containing sulfhydryl groups due to reduction of cystine residues, have been shown by Speakman and Cockburn to be strengthened by ninhydrin as well. It is suggested that this strengthening probably involves reoxidation of the cysteine residues in addition to the action of ninhydrin on the basic side chains, such as in the case of untreated fibers.

A new technique for imparting a very high degree of permanent set to strained animal fibers at low temperature, e.g., 50° C., was reported in a paper by Speakman and Speakman. The method involves treatment of the strained fibers with a solution containing sodium sulfite and ninhydrin. It is particularly interesting in that it is the first example of the setting of strained fibers by means of a combination of oxidizing and reducing agents.

Action of Dimaleimides on Wool

The use of dimaleimides as cross-linking agents for wool is discussed on page 376.

Other cross-linking reactions. Professor H. Zahn, Director of the German Wool Research Institute, gave a most informative lecture entitled "Experience with Cross-Linking Reactions in Wool." He reviewed the recent work he and his co-workers have carried out with mono- and bi-functional aromatic compounds as cross-linking agents for wool. It was pointed out that such compounds as 1,5-difluor-2,4-dinitrobenzene confer mothproofness on wool, and bischloromethyl dimethylbenzene increases the resistance of wool to rotting by bacterial attack.

Highlights of Papers on Physical and Protein Chemistry

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MY purpose here is to review very briefly some highlights of papers presented on the subject of physical and protein chemistry of wool before the International Wool Textile Research Conference held in Australia in August and September, 1955. The principal aim of research on physical and protein chemistry of wool is to obtain more complete understanding of the fiber—how it is constructed and how it behaves in diverse environments.

It is generally recognized that successful application of modern science in manufacturing industries requires much knowledge of the materials involved. It is important to gain all possible knowledge of the basis for quality of raw materials that go into processing and the changes that occur in them as they are transformed into finished products. Such information is a guide, essential for development of more efficient processing conditions and methods, for example, scouring, bleaching, dyeing, carbonizing; this information also provides a basis for developing improved finishing treatments of wool, such as modifications to impart resistance to shrinkage, yellowing, and abrasion.

Those who handle wool are accustomed to judge many of its qualities by how it feels in their hands and how it looks to their eyes. The foundation for wool quality goes deeper; it depends ultimately on the architecture of the fiber,—what it is made of and how it is put together. Also it depends on its history—on all of the conditions to which it has been exposed, on the sheep, in storage, in processing, and in use.

Some main points of the reports dealing with the molecular architecture of wool and its stability towards typical environments are summarized briefly as follows.

Despite the highly complex structure of wool, significant progress is being made in understanding details of its fine structure. This work is assisted by new techniques and new equipment in the research laboratory. The accompanying figure represents an enlarged wool fiber cut open to reveal the inside (Figure 1). A sheath of outer scales is seen to cover the outside of the fiber and to surround a core of tightly packed elongated cells. The black spots in the center of the cells represent chemical remnants of what were once nuclei of living cells. The scales and cells are fibrous in structure and consist of keratin protein, the generalized structure of which is represented in the inserted diagram. This diagram illustrates the keratin molecules as coils held together in network fashion, partly by sulfur links. The coils carry several kinds of chemically sensitive centers represented by *x*, *y*, and *z* in the diagram. If we were to use

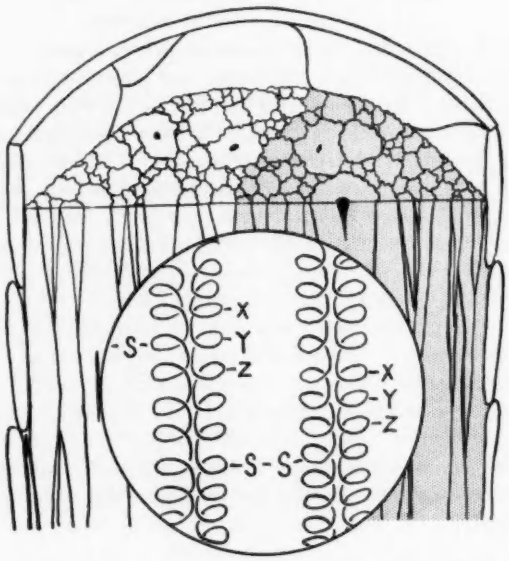

Fig. 1. Enlarged longitudinal section of a wool fiber shown schematically.

higher magnification, the elongated cells would be seen to consist of bundles of threads cemented together and lying mostly in the lengthwise direction of the cells. The scales similarly would be seen to consist of threads, but these lie in random fashion, more nearly like the fibers in leather.

The threads of the elongated cells and scales can be further subdivided into finer threads, and these in turn consist of coiled threadlike molecules. These coiled threadlike molecules comprise the heart of the wool fiber. Considerable discussion was devoted at the Conference to the properties of these molecular threads—how they coil and uncoil, how they stick together, and how they may be changed in properties by treatments with specific chemicals.

These molecular coils are protein molecules; in fact, all parts of the wool fiber are constructed of protein molecules called keratin. All protein molecules are built from chemical units called amino acids. In wool about 20 different kinds of amino acids are joined together in specific order to form the molecular threads. In papers by Simmonds of the Melbourne Wool Textile Research Laboratory, and by Corfield and Robson of the Wool Industries Research Association, Leeds, the complete amino acid analyses of wool were described.

In papers by O'Donnell, Gillespie and Harrap, all of the Melbourne Wool Textile Laboratory, and by Alexander of the Chester Beatty Institute, London, properties of the thread molecules isolated from wool were discussed. The molecules were isolated by treatments of wool with special solvents which separate the molecules from one another and dissolve them. The protein molecules which comprise wool structure can be brought into solution as single molecules when wool is treated in appropriate solvents.

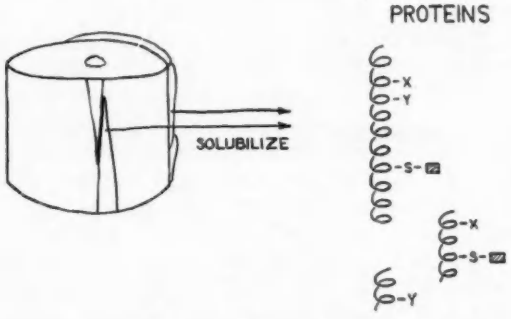

Fig. 2. Solubilization and properties of wool proteins.

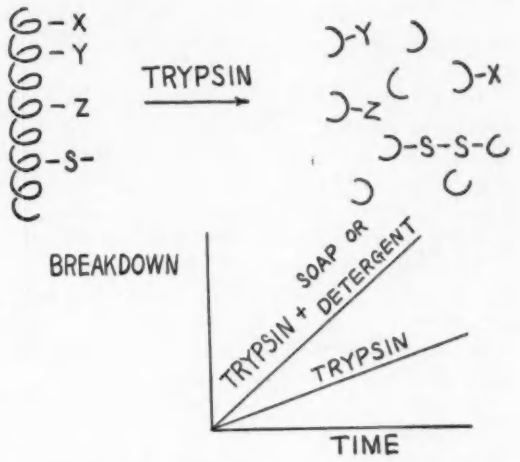

Fig. 3. Digestive breakdown of wool proteins.

The conditions for solubilization were discussed by I. J. O'Donnell and E. F. Woods of the Melbourne Wool Textile Research Laboratory.

The dissolved protein molecules, represented as coils in the diagram, vary in size and electrical charge. The electrical charge is determined by the number and kind of the ionizable groups in the coil, represented by x and y in Figure 2. The separation of similarly charged wool proteins was discussed by J. M. Gillespie of the Melbourne Wool Textile Research Laboratory.

When a protein molecule, represented by the coil in Figure 3, is treated with trypsin, an enzyme found in animal intestines, the molecule breaks up into amino acids. W. G. Crewther of the Melbourne Wool Textile Research Laboratory showed that the process of enzymatic breakdown is accelerated when a soap or detergent is present. Information from such experiments on proteins is important theoretically for assisting development of understanding of subtle differences in molecular structure and practically for development of more stable wools. Digestive breakdown is the process by which moths and microorganisms destroy wool.

Papers were presented reviewing progress in the formation of the protein threads in the follicles, which are the minute depressions in the sheep's skin. As soon as the coiled thread molecules form in the follicles they in turn join into networks and into bundles of networks. It is these networks and bundles of networks, together with a limited number of protein

molecules serving as cementing material, that make up the component parts of the wool fiber, the scales and the spindle cells.

The presence of network structure confers specific features to wool fiber. The characteristic response to applied stress is related to network structure. Wool is resilient and recovers from long-range stretching. These properties are a reflection of the coiling and uncoiling of the molecular threads. The limitations to stretching are imposed by the junctures which hold the threads in networks and limitations imposed by the presence of tightly bonded networks. Papers were presented at the Conference dealing with these interpretations of elastic properties of wool.

Professor Robert Corey of the California Institute of Technology reviewed evidence for the nature of coiling of protein thread molecules. Such evidence is obtained through methods which employ X rays, electrons, and infrared light to measure the extremely small spacings between atoms of the ultimate building material. Evidence points to a particular kind of coil, called the alpha helix. The possibility of left-handed and right-handed helices was considered by Lindley of the Melbourne Textile Research Laboratory.

Professor Henry Eyring of the University of Utah and Drs. L. Peters of Leeds University and M. Feughelman of the Wool Textile Research Laboratory, Sydney, discussed the energy of coiling and uncoiling of the molecules in relation to the mechanical properties of the wool fiber . If wool fiber is extended and held, the tension in it gradually falls. This phenomenon is called relaxation; it is of great significance in processing. Another characteristic is the extension of a fiber which occurs when a weight is hung on it. The extension increases with time; the process is called creep. The amount of creep varies with temperature and humidity. It is important to know more about relaxation and creep and the behavior of wool in bending and twisting because these changes occurring in processing affect the quality of the processed material. This information is useful to the engineer who is designing new machinery or modifying existing types. This information may also be useful for the engineering of new types of fabrics.

When a wool fiber is elongated the constituent protein molecules uncoil. The load-elongation behavior of the fiber is a reflection of the number and kind of bonds which stabilize the coiled condition and which hold the coils together. (See Figure 4.) The interrelationships between structure and elastic properties were discussed by H. Eyring of the University of Utah, Miss K. R. Makinson and M. Feughelman of the Sydney Wool Textile Research Laboratory, L. Peters of the University of Leeds, and H. Sobue of Tokyo University.

A new approach to assessment of "handle" was reported at this meeting in a paper from The Western Utilization Research Branch. The method involves analysis of the sound produced by fabrics in friction. We use a calibrated microphone to pick up the sound. The sound is analyzed in a harmonic wave analyzer and results are recorded as a spectrum of sound—the variation of intensity of sound over a range of frequency.

An additional feature of wool protein fine structure, important to understanding its behavior, is the presence of chemically sensitive centers. These centers are attached like appendages along the length of each threadlike molecule. It is at these centers that dyes, acids, alkalies, bleaches and other chemicals, including water, combine with wool. Professor Helmut Zahn, Director of the German Wool Research Institute, reviewed important contributions which he has made on the understanding of these centers. Because wool fiber is highly chemically sensitive, the history of the fiber is an important consideration. Wool goes through a long and complex route from the sheep's back until it is ready for the consumer. Throughout this course it encounters many adverse conditions. On the sheep's back, for example, wool is exposed to weathering, which includes the effects of moisture, heat, and sunlight. Wool is also exposed to effects of bacteria growing in the fleece; to medications which stain the

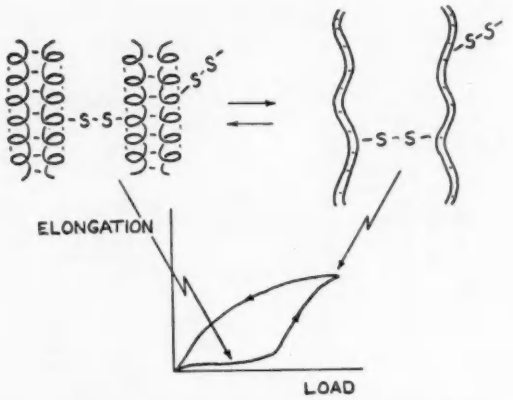

Fig. 4. Relation between fiber structure and mechanical properties.

fiber, such as phenothiazine and copper; to branding fluids, frequently not removed by scouring; and it is exposed to contamination with various kinds of soils and vegetable matter. In storage wool may be stained by constituents in the grease and suint. In the mill wool may suffer loss in strength and acquire harshness from adverse conditions of the dyebath or during bleaching or scouring. On the other hand, wool may undergo felting during scouring; this results in fiber breakage in the subsequent carding. And finally, in the consumer's hands it is well known that it may get into hot water.

All these are summed up in reduced fiber quality. It is apparent therefore that the physical-chemical investigations of the stability of wool are important, if not complex, problems.

One group of papers at the Conference dealt with the interaction of wool with water. Water can exert profound influence on wool fiber behavior. The absorption of water and water vapor by wool and also the repellency of water by wool are important considerations in the development of improved processing conditions and methods, and also in understanding the factors of quality which appeal to the consumer.

The movement of water into wool and out again is called diffusion. Diffusion sets a limit on the rate at which the regain of wool can be brought to a new value by moving wool to a dryer or wetter atmosphere. For example, Roberts and Haley of the Sydney Wool Textile Research Laboratory report that if a fiber of 64's quality with a regain of 20% is placed quickly in dry air, it takes about 3 min. for the average regain to fall 5% if kept at room temperature.

Water which enters the fiber proceeds to certain chemical sites to which part of it is bound. J. G. Downes, also of the Sydney Wool Laboratory, described a new method to measure precisely the rate at which a single wool fiber takes up moisture from the atmosphere. His studies support the idea that water is bound to wool in at least two ways—perhaps two kinds of sites.

The problem of the interaction of wool with acids was considered. Acids have long been used to assist dyeing. It is important to understand better the process of dyeing in order to develop improved conditions and methods. Acids are attracted to basic sites in the wool structure, and Larose of Laval University, Canada, discussed proposed mechanism of acid interaction. Peryman of the Wool Industries Research Association, Leeds, considered the effect of acid on the chemical and physical properties of yarn.

One of the chemical sites of wool, which is especially sensitive to some environments, is the sulfur bond. The sulfur bond consists of two sulfur atoms. It is the principal linkage which connects the threads into networks, and when these sulfur bonds are broken, wool becomes weak and loses its long-range elastic properties. A paper by Sobue of Tokyo University discussed the effect of breaking of the sulfur links on the mechanical properties of wool fibers. The sulfur links can be broken by the action of hot water, by exposure to alkaline conditions, and by contact with bleaches. By introduction of suitable chemical groups between the sulfur atoms of a disulfide linkage, the cross linking of protein coils is made more chemically stable, for example to alkali. This topic was discussed by J. B. Speakman of the University of Leeds and H. P. Lundgren. (See Figure 5.)

Peter Alexander of the Chester Beatty Institute, London, discussed the reactivity of sulfur links in relation to the effects of the chemicals surrounding them. Some of the sulfur cross links that hold the protein coils of wool together are more stable to chemical attack than others. The higher chemical stability is attributed to presence of structural barriers (see Figure 6).

It is possible to increase the stability of sulfur links by modification of the atoms in their immediate vicinity. Examples of this were given in a paper by F. L. Warburton of the Wool Industries Research Association, Leeds, which described some treated wools that are more stable to hypochlorite bleach.

Another approach is to change the sulfur link itself. A new treatment for accomplishing this was disclosed

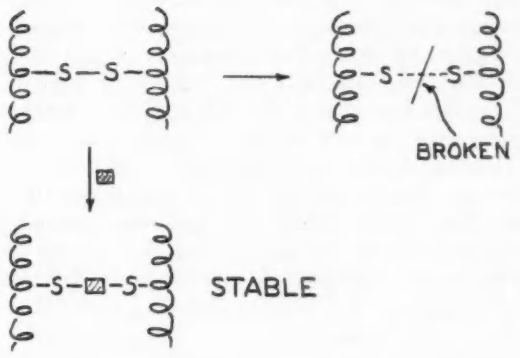

Fig. 5. Protection of the sulfur "vulcanizing" centers in wool.

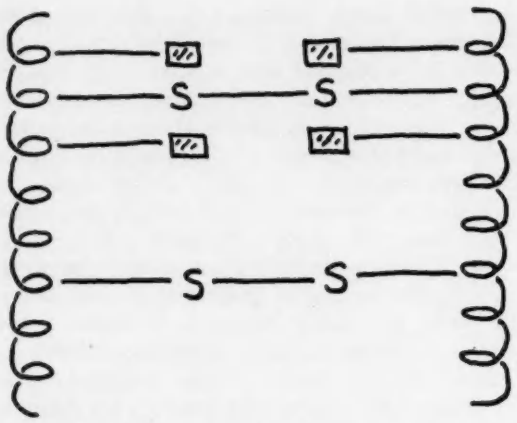

Fig. 6. Protection of sulfur "vulcanizing" centers by structural barriers. (Accessible and inaccessible disulfide links.)

in one of the papers from our laboratory. Using a new type of chemical agent, called bismaleimide, it was found possible to build new types of cross links in wool and in this way provide marked improvement of stability of wool to alkali.

Also considered at the Conference in another paper from our laboratory was the problem of off-color wools. The problem of off-color wools is important because of the demand for pastel fabrics. This problem has at least two facets: persistence of color, even in the thoroughly scoured new wool, and gradual yellowing and darkening of light wool fabrics under conditions of normal use. The yellow colors are in general not removable by washing, and are even difficult to remove by bleaching. Significant findings have been made in the understanding of the yellowing of wool promoted by wool impurities. A constituent of wool suint, urocanic acid, has been isolated in pure form and has proved to be one of the factors responsible for the yellowing of unscoured wool at moderately elevated temperatures in the presence of moisture. When small amounts of this acid are placed on clean white wool, the wool is found to undergo more rapid yellowing at the site of application. Significantly, urocanic acid is a constituent of human perspiration, and the problem of wool-fabric yellowing promoted by perspiration is generally recognized. The mechanism of the yellowing action promoted by urocanic acid is being studied in an effort to discover promising avenues of approach toward practical means for minimizing or inhibiting such yellowing.

Our paper also reported findings in investigations on yellowing promoted by exposure to short-wave light. This yellowing is readily produced by germicidal lamps emitting 90% of their radiant energy in the ultraviolet (at 2500 A).

Studies of the photochemical yellowing process in wool have revealed that the reaction leading to yellowing can be intercepted and inhibited if certain types of chemical compounds are added to the wool. The agents which have been found effective are trialkyl phosphates and tetra-alkyl titanates. Experiments have revealed that their protective action is due to the alkoxy radicals liberated from these compounds by the action of light. These alkoxy radicals are believed to intercept the photochemical activation of some wool constituent, which is the first step in the yellowing reaction. This protective action is similar to the action of antiknock compounds which prevent pre-ignition of gasoline motor fuels.

Work is proceeding in order to gain further insight into the photochemical yellowing process. Although the phosphate and titanate compounds do not appear economically feasible for commercial application, the study of these compounds establishes general principles and thus assists in the search for a practical modification of wool that will guarantee improved stability of wool towards light.

The foregoing constitute a few highlights of papers dealing with the physical and protein chemistry of wool presented before the International Wool Textile Research Conference. The information gained from these studies provides new understanding of the basis for wool quality as a raw material for manufacture. This information is essential for development of improved processing conditions and methods. The researchers are finding out where in the wool structure the modification treatments are most effective for specific purposes. They are preparing and studying new chemical agents and seeking conditions for the most efficacious treatment. All of this research is designed to assist the wool industry and at the same time satisfy consumer demands for wool products of higher quality.

Biology and Manufacture

J. Menkart

Textile Research Institute, Princeton, N. J.

THE most logical way to discuss the technological subjects considered by the Conference will be to take them in the processing sequence—touching first on wool breeding and quality evaluation, and going on from wool scouring to finishing.

Research on wool breeding was not in itself one of the Conference topics. Several facets of the problem were, however, discussed; the most important of these was the question of what properties and characteristics are to be aimed for in selective breeding. In the past, the biologist has had as his only criterion the value placed on different wool characteristics by the buyer. Some items of evidence accumulated in recent years suggest that not all the factors valued in the auction room are a true guide to the technological performance of the fiber, and that other important ones may be ignored. The biologist wishes to be certain that when he aims at a certain result (e.g., increased fleece density), he does not inadvertently cause a deterioration in some important but overlooked property of the wool. The biologist's view was put forward by Turner and Schinckel; Bray summarized the present knowledge of the technological importance of various fiber properties, and the relationship of these properties to the factors evaluated by the breeder, classer, and buyer. The outstanding impression of these discussions was the need for much new information in two fields: firstly, relation between fleece and staple characteristics on the one hand and fiber characteristics on the other; and secondly, the effect of fiber properties on processing performance and product quality.

Aspects of sheep-raising practice important to the manufacturer were mentioned in other papers. For instance, Story discussed experiments on pre-lamb shearing in New Zealand; this places the "break" in the wool which occurs at lambing time at the tip of the staple and thus diminishes its deleterious effect. Bownass showed that double clips (second cuts) account for about 2% of the weight of a typical batch of Australian Merino wool; an experiment in which this material had been eliminated by hand sorting resulted in a corresponding improvement in noilage.

The development of scourable sheep-branding fluids at the Geelong laboratory of CSIRO and their field application were summarized by Lipson. The present formulation (SI-RO-MARK) is a water-in-oil emulsion with a lanoline base; under Australian conditions—dense Merino fleeces and low rainfall—it performs satisfactorily in the field. Its scourability was effectively demonstrated by the presentation to the delegates of a Conference tie made of brands, soap-and-soda scoured. The problem of adulteration in the shearing shed is being reduced by excluding black from the colors used.

Two methods of solvent scouring were brought to the attention of the Conference. In the Swedish one, discussed by Lindberg, the wool is passed through a bath of the solvent by means of a perforated rotating drum. It is then centrifuged and air-dried, and goes on to carding without any contact with water. Possible difficulties are evident, due to the residual solvent (a high-boiling petroleum product) evaporating on the card and to the tacky nature of the suint remaining on the wool, but it is claimed that no insuperable problems have been encountered in practice.

The Australian solvent-scouring technique, described by Sinclair, utilizes curtains of solvent (white spirit) impinging under pressure onto the wool traveling on a wire mesh conveyor. After passing between squeeze rolls, the wool is subjected to a similar jetting with cold water, squeezed again, and conventionally air-dried. The mechanical action of the solvent and water results in the removal of much of the solid dirt as well as of the grease and suint. A pilot plant (200 lb. greasy/hour) was operating in Geelong, and the wool emerging from the drier was satisfactorily clean and very open, with only slightly cotted tips, which are apparently dealt with satisfactorily in backwashing. A substantial decrease in noilage, compared with emulsion scouring and a comparative cost level, is claimed for this method.

Veldsman and Palmer presented a group of rapid analytical methods for wool scouring. One of these —the Column-and-tray method for the residual grease content of wool—had been described earlier; pro-

cedures have now been added to this for determining the residual alkali and residual soap in wool, the grease content of effluent, and the water content of centrifuged wool grease. All these techniques yield results within a small fraction of the time taken by the conventional procedures and, thus, are capable of being used for process control. The recovery of lanoline by a flotation method was discussed by Anderson; the effectiveness of this procedure appears to depend considerably on the composition of the liquor, and its applicability may be limited on this account.

Crewther reported on work dealing with the effect of surface-active agents in carbonizing; the damage suffered by the wool (loss in weight and loss in strength) is reduced by the presence of surfactants in the liquor, whilst the carbonization of the cellulose seems unaffected. This study was on a laboratory scale, and further pilot-plant work is needed to ascertain that no unforeseen complications are encountered in practice; however, it seems to have practical possibilities.

The problem of burrs in wool is being attacked not only by studies of the carbonizing process, but also by investigating the burrs themselves. Thus, Pressley had observed wide variations among burrs of one type (the common round burr), but of different maturities and from a range of localities, in the adsorption of acid and consequently in the ease of carbonization. Attention to this point in the selection of strains of grasses and clovers for pastures may be of benefit to the manufacturer in the long run. A more radical approach consists in the attempt to develop a strain of clover with seeds not tending to adhere to the fleece (which might be achieved by eliminating or modifying the hooks on the seed). It was mentioned during the Conference that such work is in progress in Australia; clearly, a solution on these lines would represent the most satisfactory answer to carbonizing problems.

Of interest for both carbonizing and dyeing is a method developed by Oku and Shimizu for the determination of mineral acid in wool, based on the ion exchange principle. It is simple, rapid, and apparently comparable in accuracy with the conventional methods.

Several studies of the fiber configuration in mechanical processing were reported: Townend and Judson had examined the effect of direction of sliver feed in top making, and determined the form and amount of hooked fibers present. The general picture which emerged was in broad agreement with the earlier observations by Morton on rayon and cotton. Two interesting points which may be mentioned were: firstly, improving the straightness of fibers entering the comb by several additional gillings brings about a considerable decrease in noilage; and secondly, that combing performance is better when the sliver is fed into the comb in the usual way, i.e., with the trailing end at the card becoming the leading end at the comb, than in the reverse situation. This suggests that an even number of processes (including punching) should always occur between carding and Noble combing. Chaikin, *et al.* had investigated the changes in fiber form in the course of worsted drawing and in the aging of slivers, rovings, and yarns by the use of fibers labeled with radioactive tracers.

Hannah discussed the theory of high drafting and its application to the Ambler Superdraft systems. An experimental study of spindle drafting was described by Angus and Martindale; investigating both the forces generated whilst the slubbing is drawn and the levelness of the product under various drafting conditions, they have thrown much light on the process. They found that in the drafting against twist, the levelness of the strand improves, in agreement with general belief of the operation of the "spinner's rule." If the operation is carried beyond a certain point, however, the optimum point is overshot and the product becomes less level again, presumably because the drawing out of the original thick places is taking place more rapidly than the consequent twist redistribution. Thus, the thick places in the sliver become thin places in the yarn. The simple device employed by Angus and Martindale in these studies may well be useful for determining the optimum mule settings for spinning any particular material.

A photoelectric particle-counting device, intended for measuring the neppiness carded web, was described by Chamberlain and Jordanides. Ill-defined "particles," such as neps, present serious problems, but these appear capable of solution.

King and Medley described an investigation of the mechanism of fiber pickup by drafting rollers. The influence of oil and static was examined; both increase the tendency to pick up and their combined effect is much greater than the sum of the individual effects. A paper by Menkart and Whitwell dealt with the problems encountered in the evaluation of the relative spinning performance of several lots of roving, and described an experimental layout and statistical procedure found suitable for the purpose.

Two new methods of controlling the levelness of textile products were described. Thorndike, Richards, and Jowett discussed the operation of the WIRA "Autocount," a device which measures photoelectrically the density of the web emerging from the doffer of a woolen card, and regulates the speed of the doffer and condenser to maintain a constant value. Variations along the web, due to misweighs, changes in hopper loading, etc., are thus largely ironed out. The other regulating devices of the card cannot, of course, be allowed to malfunction with complete impunity: a card which is running on tends to retain the longer and/or finer components of a blend, and pass forward preferentially the shorter, and/or coarser ones; the converse holds during running off. (This subject, as well as a number of other aspects of mixing in the woolen system, was discussed by Townend.) Thus, variations in the composition of the card output can occur in spite of the maintenance of constant weight per unit length.

The second control device, the use of which in different systems of worsted processing was surveyed by Feather, was the Raper autoleveller. This is a sliver thickness-sensing element positioned on the input side of a drafting zone, which through mechanical linkages alters the draft in accordance with the variations in the weight of the incoming sliver.

The two systems just mentioned are, it is to be hoped, symbolic of a change in attitude in textile engineering. They represent a departure from the reliance on the law of averages, which has up to now been the sole mechanism for improving the uniformity of a textile product from one process to the next.

Various aspects of shrinkproofing with resins were covered by the Australian workers. Particularly interesting were two complementary papers by Jackson and Makinson. Jackson had investigated the nonshrink effectiveness of a number of resin treatments over a range of conditions of application. He found that some of those studied required a pretreatment of the wool—solvent extraction, or chemical attack—to give satisfactory shrink-resistance; others were equally effective whether or not the wool had been pretreated. He suggested that in the first group, the resin is attached to the fiber solely by adhesion, whereas in the second group (which was comprised of polyurea, silane, and polyglycine) chemical combination between wool and resin occurs. Makinson made a microscopic examination of the treated materials, and found that in group one, the resin was in each case present as a discontinuous deposit on the fiber surface, bonding fibers together; in group two, the resin formed a continuous coating on the fiber surface, and presumably eliminates felting by masking the scales rather than by bonding fibers together.

Two interesting investigations in the field of mothproofing were presented by Lipson. The first dealt with certain anionic surface-active agents which, when applied to wool under acid conditions at elevated temperature, give resistance to larval attack. Wash and light fastness is limited, but the technique may have some use for temporary protection. The second study was concerned with the insecticides Aldrin, Dieldrin, and Endrin. Dieldrin was found to be a potent larvicide for both the cloth moth and the carpet beetle; against expectation, it turned out to have a high fastness to washing and dry cleaning. In view of the known toxicity of this agent to humans, some careful studies are clearly needed before its practical potentialities can be assessed.

Appendix A

List of Technical Papers Presented at the International Wool Textile Research Conference, August–September, 1955

SYDNEY

Tuesday, August 23

Session 1. STUDIES ON SOLUBLE PROTEINS
Chairman: Dr. F. W. G. White

Dr. R. L. M. Synge, Rowett Research Institute, Aberdeen, "Secondary-Valence Interactions and the Separation of Larger Peptides."

Dr. F. G. Lennox, CSIRO, Melbourne, "The Wool Protein Complex and its Hydrothermal Instability."

J. M. Gillespie, CSIRO, Melbourne, "The Electrophoretic Properties of Kerateine 2 (Component 2) and Some of its Derivatives."

I. J. O'Donnell and E. F. Woods, CSIRO, Melbourne, "Preparation of Wool Protein Solutions."

Dr. W. H. Ward and Dr. H. P. Lundgren, U.S. Dept. of Agriculture, "Studies of the Molecular Kinetic Units of Wool."

Dr. A. J. P. Martin and Dr. R. R. Porter, National Institute for Medical Research, London, "Partition Chromatography of Proteins."

Session 2. STUDIES ON SOLUBLE PROTEINS (continued)
Chairman: Prof. J. B. Speakman

Dr. P. Alexander and Dr. L. F. Smith, Chester Beatty Research Institute, London, "Macromolecular Structure of Wool. The Terminal Amino Acids of the Fraction Obtained after Oxidation with Peracetic Acid."

I. J. O'Donnell and E. F. Woods, CSIRO, Melbourne, "A Physicochemical Study of the Soluble Protein from Peracetic Acid-Oxidised Wool."

Dr. B. S. Harrap, CSIRO, Melbourne, "Molecular Weights of Some Wool Derivatives."

Prof. H. Zahn and J. Meienhofer, University of Heidelberg, "Wool Gelatin, I. Isolation of Acid Peptides from Cold Water Extracts."

Dr. F. Happey, Bradford Technical College, "Some Practical Aspects of the Regeneration of Protein Fibres."

Dr. A. G. Ogston, Oxford University, "Remarks on the Definition and Measurement of the Solvation of Macromolecules in Solution."

Session 3. ELASTIC PROPERTIES OF WOOL
Chairman: Prof. N. H. Nissan

Dr. A. L. Ruoff and Prof. H. Eyring, University of Utah, "The Mechanical Properties of the α-β Transformation in Natural Keratin Fibres."

Dr. C. E. Reese, Dr. A. L. Ruoff, and Prof. H. Eyring, University of Utah, "The Mechanical Behaviour of Polyacrylonitrile Fibres in the Presence of an External Plasticizer (Water)."

F. L. Warburton, Wool Industries Research Association, Leeds, "The Vibrational Behaviour of a Three Element Visco-Elastic Model and its Application to Vibration Experiments on High Polymers."

K. Rachel Makinson, CSIRO, Sydney, "Some Speculations on Possible Instability Phenomena in the Mechanical Behaviour of Proteins."

M. Feughelman and B. J. Rigby, CSIRO, Sydney, "A Two-Energy-State Model for the Stress Relaxation and Creep of Wool Fibres in Water."

Dr. L. Peters, The University, Leeds, "A Molecular-Mechanical Model of Wool Keratin."

Wednesday, August 24

Session 4. THE PROBLEMS OF THE PRODUCER AND BIOLOGIST IN MEETING THE NEEDS OF THE TEXTILE INDUSTRY
Chairman: Sir Ian Clunies-Ross

Miss Helen N. Turner, CSIRO, Prospect, "Some Aspects of the Relationship between Textile Research and Biological Research on Wool Production."

P. G. Schinckel, CSIRO, Prospect, "Aspects of the Biology of Wool Production."

Dr. C. E. Terrill, Mary E. Hourihan, F. E. White, and T. D. Watkins, Jr., U.S. Sheep Experiment Station, Idaho, "Heritability and Relationship to Other Traits of Carding and Combing Yields of Main Sorts of Individual Targhee Fleeces."

Dr. L. F. Story, N. Z. Woollen Mills Research Association, Otago, "Effect of Shearing Time on Wool in New Zealand."

Prof. A. L. Rae, Dr. F. W. Dry, and Dr. F. R. Cockrem, Massey Agricultural College, Palmerston North, N.Z., "Some Problems of Wool Production in Dual-Purpose Sheep."

Session 5. THE PROBLEMS OF THE PRODUCER AND BIOLOGIST IN MEETING THE NEEDS OF THE TEXTILE INDUSTRY (continued)
Chairman: Sir Ian Clunies-Ross

R. T. Bray, International Wool Secretariat, "Wool Characteristics in Relation to Manufacturers' Requirements."

W. R. Lang, Gordon Institute of Technology, Geelong, "Merino Wool Bulks: The Technological Relevance of the Formal Physical Characteristics of the Fibre."

N. F. Roberts and Dr. A. A. Dunlop, CSIRO, Sydney and Prospect, "Relations Between Crimp and Fineness in Australian Merinos."

W. R. Hindson and F. S. Young, Dept. of Supply, Defence Standards Laboratory, Melbourne, "The Estimation of Wool Quality from Measurements of Fibre Diameter."

E. M. Pohle, D. D. Johnston, H. D. Ray, W. A. Mueller, H. C. Reals, and W. J. Manning, Livestock Division, Wool Laboratory, U.S.D.A., "Fineness Relationship of Raw Wool, Top, Noil, and Per Cent Noilage."

N. F. Roberts, CSIRO, Sydney, "The Physical Characteristics Determining the Softness of Handle of Wool"; and "Yield Errors of Estimation by Wool Buyers."

S. S. Y. Young and Dr. A. A. Dunlop, CSIRO, Prospect, "The Relation of Some Characteristics of Merino Wool to Prices Paid at Australian Sales."

Prof. P. R. McMahon, N.S.W., University of Technology, "The Importance of Subjective Appraisal in Wool Research and Wool Commerce."

R. Bownass, Wool Industries Research Association, Leeds, "The Effect of Double Clips on Worsted Processing."
Dr. S. B. Slen, Wool Research Laboratory, Alberta, "The Relationship of Staple Size to Certain Fleece Characteristics in Rambouillet Sheep."
Dr. S. Nakahara, Ibaragi University, "Silk Worm Faeces as a Supplementary Diet for Sheep."

Thursday, August 25

Session 6. HISTOLOGY OF THE SHEEP FOLLICLE
Chairman: Dr. A. B. Wildman

Dr. K. M. Rudall, The University, Leeds, "The Size and Shape of the Papilla in Wool Follicles."
Dr. Margaret H. Hardy and A. D. Lyne, CSIRO, Sydney, "The Histological Development of the Skin and Wool in the Merino Foetus"; and "The Development of Wool Follicles from Foetal Sheep Skin in Tissue Culture."
Dr. L. Auber and M. L. Ryder, Wool Industries Research Association, Leeds, "Anomalies in the Structure and Development of Wool Fibres."
M. L. Ryder, Wool Industries Research Association, Leeds, "The Blood Supply to the Wool Follicle."

Session 7. SOME PHYSICAL PROPERTIES OF WOOL FIBRES, YARNS, AND FABRICS
Chairman: Dr. J. H. Dillon

Dr. R. W. Burley, CSIRO, Pretoria, "Some Observations on the Extension, Contraction, and Supercontraction of Wool Fibres."
G. W. Walls, CSIRO, Geelong, "An Investigation of the Load-Extension Curve for Wool Fibres Over the Decrimping Range."
Prof. J. Meybeck and G. Gianola, Centre de Recherche Textile, Mulhouse, "Contribution to the Study of the Breaking Stress of Wool Fibres as a Function of Their Diameter."
Dr. H. F. Schiefer, National Bureau of Standards, U.S.A., "Stress-Strain Relationships in Yarns Tested at Rates of Straining up to a Million Per Cent per Minute."
T. V. Ananthan and W. R. Lang, Gordon Institute of Technology, Geelong, "The Physical Properties of Woollen Fabrics: The Effect of Weave and Sett on Tensile Strength."
W. J. Thorsen and Dr. H. P. Lundgren, U.S. Dept. of Agriculture, "Analysis of Sound Spectra of Wool Fabrics in Friction."

Session 8. REACTIVITY OF THE DISULPHIDE BOND IN PROTEINS AND PEPTIDES
Chairman: Prof. J. B. Speakman

Prof. A. Schöberl and Annemarie Wagner, Veterinary High School, Hanover, "Studies on Lanthionine Formation from Wool and Cystine."
Prof. H. Zahn, University of Heidelberg, "New Methods of Lanthionine Formation in Wool."
Dr. J. M. Swan, CSIRO, Melbourne, "The Synthesis and Lanthionine-Forming Properties of Some Derivatives of Cystine."
Dr. P. Alexander and Dr. M. Fox, Chester Beatty Research Institute, London, "A Comparison of the Reactivity of the Disulphide Bond in Wool with that in Peptides."
Dr. F. Sanger, Dr. A. P. Ryle, Dr. L. F. Smith, and Miss Ruth Kitai, Cambridge University, "The Distribution of the Cystine Residues in Insulin."
Prof. H. Sobue, Tokyo University, "Effect of the Breaking of Cystine Linkages on the Mechanical Properties of Wool Fibres."

Session 9. DYEING AND FINISHING
Chairman: Dr. E. G. Carter

Dr. J. Lindberg, Swedish Textile Research Institute, Gothenburg, "Engineering Principles in Dyeing and Wet Finishing."
Dr. P. Larose and Miss Rita Donovan, National Research Council, Ottawa, "Observations on the Sorption of Acids by Wool."
Dr. P. Larose, National Research Council, Ottawa, "The Change in Diameter of Wool Fibres on Dyeing."
Dr. R. V. Peryman, Wool Industries Research Association, Leeds, "Changes in the Properties of Wool in Dyeing and Related Processes"; and "A Study of the Chroming of Wool."

GEELONG

Wednesday, August 31

Session 10. CARDING, DRAFTING, AND SPINNING
Chairman: Dr. P. P. Townend

J. Ingham, Wool Industries Research Association, Leeds, "A Review of Worsted Open Drawing and Spinning."
Dr. Margaret Hannah, The University, Leeds, "High Drafting in Theory and Practice."
J. Angus and Dr. J. G. Martindale, The Scottish Woollen Technical College, Galashiels, "Spindle Drafting of Woollen Slubbings."
Dr. J. Menkart and Prof. J. C. Whitwell, Textile Research Institute, Princeton, "The Design and Analysis of a Spinning Experiment."
G. H. Thorndike, R. T. D. Richards, and P. D. Jowett, Wool Industries Research Association, Leeds, "Automatic Control of the Output Levelness of a Woollen Card."

Session 11. FINE HISTOLOGY OF WOOL AND HAIR
Chairman: Dr. A. B. Wildman

N. Ramanathan, Dr. J. Sikorski, and H. J. Woods, The University, Leeds, "The Surface Structure of Wool Fibres."
Dr. E. H. Mercer, Dr. J. L. Farrant, and Dr. A. L. G. Rees, CSIRO, Melbourne, "The Fine Histology of Wool."
Dr. R. D. B. Fraser and G. E. Rogers, CSIRO, Melbourne, "New Aspects of the Fine Histology of Wool."
A. Durward and Dr. K. M. Rudall, The University, Leeds, "The Axial Symmetry of Animal Hairs."
G. M. Jeffrey, Dr. J. Sikorski, and H. J. Woods, The University, Leeds, "The Microfibrillar Structure of Keratin Fibres."

Session 12. INTERACTION OF WOOL AND WATER
Chairman: Dr. J. G. Martindale

Dr. T. Ree and Prof. H. Eyring, University of Utah, "Generalized Theory of Viscosity and Diffusion."
A. R. Haly and N. F. Roberts, CSIRO, Sydney, "Interaction of Wool and Water. I. The Diffusion of Water in Wool Fibres."

A. R. Haly, CSIRO, Sydney, "Interaction of Wool and Water. II. Rates of Swelling of Single Fibres Following Absorption of Water from the Liquid Phase."
J. G. Downes and B. H. Mackay, CSIRO, Sydney, "Interaction of Wool and Water. III. Rates of Sorption of Water Vapour by Wool Fibres."
M. Leveau, N. Varney-Cebe, and A. Parisot, Institut Textile de France, Paris, "New Studies on the Swelling Properties of Wool Fibres."
F. L. Warburton, Wool Industries Research Association, Leeds, "Heat and Moisture Relations for Textiles."

Thursday, September 1

Session 13. WET PROCESSING OF WOOL
Chairman: Dr. C. S. Whewell

Dr. F. O. Howitt, Wool Industries Research Association, Leeds, "The Scouring of Raw Wool."
Dr. M. Lipson, CSIRO, Geelong, "Sheep Branding Fluids."
D. P. Veldsman and R. C. Palmer, Wool Textile Research Institute, South Africa, "Rapid Methods for Control in Wool Washing."
Dr. K. J. Lindberg, Swedish Institute for Textile Research, Göthenburg, "The Swedish Solvent Scouring Process."
J. F. Sinclair, CSIRO, Geelong, "A Method for Solvent Degreasing of Wool."
C. A. Anderson, CSIRO, Geelong, "Recovery of Lanoline from Wool Scour Liquors."

Session 14. WET PROCESSING OF WOOL (continued)
Chairman: Dr. C. S. Whewell

K. Lees and Dr. F. F. Elsworth, Wool Industries Research Association, Leeds, "The Correlation of the Alkali Solubility of Wool and its Resistance to Abrasion."
Prof. M. Oku and I. Shimizu, Kobe University, "The Action of Hexamethylenetetramine on Greasy Wool and its Effect on Scouring and Carbonizing."
T. A. Pressley, CSIRO, Melbourne, "Carbonizing Investigations. II. The Absorption of Sulphuric Acid by Wool and Trefoil Burr."
Gwynfred Jones, Gordon Institute of Technology, Geelong, "The Absorption of Sulphuric Acid by the Burrs of *Medicago minima* and its Significance in the Carbonizing Process."
W. G. Crewther, CSIRO, Melbourne, "Carbonizing Investigations. III. A New Method for Protecting Wool During Carbonizing."
Prof. M. Oku and I. Shimizu, Kobe University, "A New Method for the Determination of Residual Mineral Acids in Wool."

Session 15. THE BEHAVIOUR OF WOOL FIBRES DURING MECHANICAL PROCESSING
Chairman: V. D. Burgmann

Dr. M. Chaikin, A. G. Stutter, K. Baird, and J. Curtis, CSIRO, Sydney, "Configuration and Strain Analysis of Single Wool Fibres in Worsted Processing."
Dr. P. P. Townend and J. Judson, The University, Leeds, "Fibre Arrangement in Worsted Processing and its Effect on Tear in Noble Combing."
G. King and J. A. Medley, Wool Industries Research Association, Leeds, "Some Factors which Influence Fibre Pick-up by Drafting Rollers."
R. Bownass, Wool Industries Research Association, Leeds, "Fibre Breakage in Early Worsted Processing."
Dr. P. P. Townend, The University, Leeds, "The Mixing Problem in Woollen Yarn Production."
W. H. Chamberlain and C. Jordanides, The University, Leeds, "The Determination of Neppiness in Carded Webs."
E. E. Feather, Prince-Smith and Stells Ltd., Keighley, "Textile Machinery Development Affecting the Processing of Fibers in Worsted Manufacture."

Friday, September 2

Session 16. AMINO ACID AND FUNCTIONAL GROUP ANALYSIS OF PROTEINS
Chairman: Dr. A. J. P. Martin

Dr. D. H. Simmonds, CSIRO, Melbourne, "Variations in Amino Acid Composition of Merino Wool"; and "Amino Acid Composition of Wool Fractions."
Dr. S. J. Leach, CSIRO, Melbourne, "Amide Nitrogen in Proteins"; and "Estimation of Cystine by Polarography."
M. C. Corfield and Dr. A. Robson, Wool Industries Research Association, Leeds, "Amino Acid Composition of Wool Keratin."

Session 17. AMINO ACID AND FUNCTIONAL GROUP ANALYSIS OF PROTEINS (continued)
Chairman: Dr. R. L. M. Synge

Dr. E. O. P. Thompson, CSIRO, Melbourne, "Studies on the Estimation of Cystine and Lanthionine."
E. R. Fritze and Prof. H. Zahn, University of Heidelberg, "The Dinitrophenylation of Wool."
H. Zuber, K. Traumann, and Prof. H. Zahn, University of Heidelberg, "Detection and Estimation of Cysteine in Wool."
Dr. S. Blackburn and G. R. Lee, Wool Industries Research Association, Leeds, "Chromatography on Ion-exchange Resins Applied to the Reaction of Wool Keratin with Alkali"; and "The Carboxyl Terminal Groups of the Peptide Chains of Wool Keratin."

MELBOURNE

Monday, September 5

Session 18. THE BILATERAL STRUCTURE OF WOOL
Chairman: Dr. H. P. Lundgren

Dr. J. H. Dusenbury and Dr. J. Menkart, Textile Research Institute, Princeton, "The Present State of the Ortho- and Para-Cortex Concept."
Dr. R. D. B. Fraser and G. E. Rogers, CSIRO, Melbourne, "The Bilateral Structure of Wool Cortex."
Dr. A. B. Wildman, Wool Industries Research Association, Leeds, "The Structure and Identification of Wool and Other Animal Textile Fibres."
Dr. K. M. Rudall, The University, Leeds, "The Keratinization of Horn."
Dr. G. Laxer and Prof. C. S. Whewell, The University, Leeds, "Some Physical and Chemical Properties of Pigmented Animal Fibres."

Session 19. AMINO ACIDS AND PEPTIDES
Chairman: Dr. F. Sanger

Prof. H. Zahn and F. Osterloh, University of Heidelberg, "Some New Derivatives of Lanthionine."

Dr. J. A. Maclaren, Dr. W. E. Savige, and Dr. J. M. Swan, CSIRO, Melbourne, "Some Observations on the Synthesis of Cystine-Containing Peptides."
Dr. J. A. Maclaren, CSIRO, Melbourne, "Preparation of the Tetraethylpyrophosphite Reagent."
Dr. J. M. Swan, CSIRO, Melbourne, "The Synthesis of L-Glutaminylglycine and L-Isoglutaminylglycine."

Tuesday, September 6

Session 20. X-RAY AND INFRA-RED INVESTIGATION OF PROTEIN STRUCTURE
Chairman: Prof. H. G. Zahn

Prof. W. T. Astbury, The University, Leeds, "X-rays and the Stoichiometry of Keratins. A Renewed Enquiry."
Dr. R. G. Marsh, Prof. R. B. Corey, and Prof. L. Pauling, California Institute of Technology, "The Structure of Tussah Silk Fibroin (with a note on the Structure of β-Poly-L-alanine)."
Dr. H. Lindley, CSIRO, Melbourne, "Some Possible Modifications of the α-Helix."
Dr. F. Happey, Bradford Technical College, "Fibre Formation in Some Natural and Synthetic Polypeptides."
Dr. S. G. Tomlin, University of Adelaide, "The Structure of Collagen Fibres."

Session 21. X-RAY AND INFRA-RED INVESTIGATION OF PROTEIN STRUCTURE (continued)
Chairman: Prof. H. G. Zahn

Dr. R. D. B. Fraser, CSIRO, Melbourne, "Molecular Orientation and Configuration in Keratin" and "The Infra-red Spectra of Fibrous Proteins in the 2μ Region."
M. Feughelman, CSIRO, Sydney, "Dipole Interaction of Amide Groups in Keratin."
D. S. Barmby and G. King, Wool Industries Research Association, Leeds, "The Effect of Strong Swelling Agents on the Infra-red Absorption of Nylon."

Thursday, September 8

Session 22. ENZYME AND PROTEIN CHEMISTRY
Chairman: Dr. A. G. Ogston

Prof. Emil L. Smith and Dr. J. R. Kimmel, University of Utah, "Some Enzymatic and Chemical Properties of Crystalline Papain."
Dr. P. H. Springell, CSIRO, Melbourne, "Enzymatic Degradation of Collagen."
Dr. B. S. Harrap, CSIRO, Melbourne, "A Study of the Unimolecular Films of Insulin at the Air-Water Interface."
Dr. S. J. Leach, CSIRO, Melbourne, "Kinetics and Mechanism of Aspartic Acid Liberation from Proteins."

Session 23. THE CHEMICAL MODIFICATION OF WOOL
Chairman: Dr. H. Eyring

W. G. Crewther, CSIRO, Melbourne, "Pretreatments which Affect the Susceptibility of Wool to Proteolysis. The Effect of pH, Wetting Agent, and Solvent Extraction."
L. Wikström, E. Sörvik, Margareta Cednäs, and Dr. B. Olofsson, Swedish Textile Research Institute, Gothenburg, "Chemical Modifications of the Surface Layers of Wool and their Effect on Wettability and Sorption Properties."
R. Bentham, C. B. Stevens, and Prof. C. S. Whewell, The University, Leeds, "Some Observations on the Degradation of Wool by Hypochlorite with Special Reference to the Action of Hypochlorite on Chemically-Modified Wool."
Prof. M. Oku and I. Shimizu, Kobe University, "Chemical Modification of Wool by Formalization with Hexamethylenetetramine"; and "Changes in the Properties of Wool with Methylation."
R. S. Asquith and Prof. J. B. Speakman, The University, Leeds, "Cross-Linking Reactions in Keratin. I. The Chemical Mechanism of Permanent Set."
H. R. Richards and Prof. J. B. Speakman, The University, Leeds, "Cross-Linking Reactions in Keratin. II. The Action of Formaldehyde on Wool."

Session 24. THE CHEMICAL MODIFICATION OF WOOL (continued)
Chairman: Prof. A. Schöberl

Dr. R. Cockburn and Prof. J. B. Speakman, The University, Leeds, "Cross-Linking Reactions in Keratin. III. The Action of Ninhydrin on Wool" and IV. "The Action of Ninhydrin on Reduced Wool Fibres."
Dr. P. T. Speakman and Prof. J. B. Speakman, The University, Leeds, "Cross-Linking Reactions in Keratin. V. A New Method of Setting Strained Fibres at Low Temperatures."
K. Lees and Dr. F. F. Elsworth, Wool Industries Research Association, Leeds, "The Solubility of Wool in Urea-Bisulphite Solutions and its Use as a Measure of Fibre Modification."
J. E. Moore and Dr. H. P. Lundgren, U.S. Dept. of Agriculture, "Dimaleimides as Cross-Linking Agents for Reduced Wool."

Friday, September 9

Session 25. SHRINKPROOFING AND MOTHPROOFING OF WOOL
Chairman: Dr. K. J. Lindberg

D. L. C. Jackson, CSIRO, Geelong, "The Prevention of Felting with Resins and the Significance of Pretreatment"; and "The Effect of Casein Shrinkproofing Treatment on the Properties of Wool."
K. Rachel Makinson, CSIRO, Sydney, "The Ways in Which Resins Prevent Felting."
H. W. Davidson and R. Preston, Wool Industries Research Association, Leeds, "Shrink-resisting Wool: A. Introduction and Brief Review. B. A New Process Based on Pretreatment with Peracetic Acid."

Session 26. SHRINKPROOFING AND MOTHPROOFING OF WOOL (continued)
Chairman: W. R. Lang

J. Delmenico, CSIRO, Geelong, "Pilot Scale Shrinkproofing Treatments of Wool. I. Application of Methoxymethylnylon" and II. "An Improved Method of Treatment with Alcoholic Alkali."
Dr. M. Lipson, CSIRO, Geelong, "Mothproofing of Wool. I. The Application of Anionic Surface Active Agents."
Dr. M. Lipson and Miss R. J. Hope, CSIRO, Geelong, "Mothproofing of Wool. II. The Effect of Dieldrin and Related Compounds."

Appendix B

List of Lectures

SYDNEY

Monday, August 22

Professor W. T. Astbury, The University, Leeds, "In Praise of Wool."

Dr. H. P. Lundgren, U.S. Dept. of Agriculture, "Advancing Frontiers in Wool Chemistry."

Tuesday, August 23

Professor H. Eyring, University of Utah, "A Statistical-Mechanical Theory of Visco-Elastic Behaviour."

Wednesday, August 24

Professor J. B. Speakman, The University, Leeds, "The Future of Wool." (Wallace Theatre, University of Sydney).

Thursday, August 25

Dr. R. L. M. Synge, Rowett Research Institute, Aberdeen, "The Principles of Chromatography." (Jointly with the Royal Australian Chemical Institute at the N.S.W. University of Technology, Kensington.)

GEELONG

Thursday, September 1

Symposium With Textile Manufacturers, Gordon Institute of Technology, Geelong
Chairman: Dr. M. Lipson, CSIRO, Geelong

Dr. A. B. D. Cassie, C.B.E., Wool Industries Textile Association, Leeds, "Worsted Processing."

Professor C. S. Whewell, The University, Leeds, "Wet Processing."

Dr. J. G. Martindale, The Scottish Woollen Technical College, Galashiels, "Woollen Processing."

MELBOURNE

Monday, September 5

Dr. E. G. Carter, International Wool Secretariat, "Wool Science and Wool Supremacy." (Public Lecture Theatre, University of Melbourne.)

Tuesday, September 6

Professor Robert B. Corey and Professor Linus Pauling, California Institute of Technology, "Configurations of Polypeptide Chains in Proteins."

Dr. F. Sanger, Cambridge University, "The Structure of Insulin."

Wednesday, September 7

Professor Emil L. Smith, University of Utah, "Leucine Amino-peptidase; Specificity, Mechanism of Action and Use in Study of Peptide and Protein Structure." (Jointly with the Royal Australian Chemical Institute, Chemistry Department, University of Melbourne.)

Thursday, September 8

Professor H. Zahn, University of Heidelberg, "Experience with Cross-Linking Reactions in Wool."

Summer Program at Massachusetts Institute of Technology

A two-week summer program, "Selected Topics in Textile Technology," will be given at the Massachusetts Institute of Technology from August 20 through August 31, 1956.

The program is directed primarily to research and development workers in fiber producing, yarn and cloth fabricating, and textile machine manufacturing industries. Topics include statistics, microscopy, dynamic behavior and mechanics of textile structures, processing dynamics, and general instrumentation. Edward R. Schwarz, Professor of Technology in Charge of the Textile Division, and Stanley Backer, Associate Professor of Mechanical Engineering, will supervise the program.

Details and application blanks for the program may be obtained from the Summer Session Office, Room 7-103, Massachusetts Institute of Technology, Cambridge 39, Mass.

National Cotton Council of America

Seventh Cotton Research Clinic

The papers in this issue comprise those given at the Symposium on High Production Drawing at the Seventh Cotton Research Clinic of the National Cotton Council of America, held in Pinehurst, N. C., February 15–17, 1956. Additional papers presented at the Clinic will appear in the June issue. Reprints of the entire proceedings, bound in a cover, will be distributed through the Cotton Council upon completion of the series.

High Production Drawing: Some Fundamental Considerations

L. H. Hance[1]

Institute of Textile Technology, Charlottesville, Va.

Introduction

Over the past several years, and especially during recent months, considerable attention has been drawn to the possibilities of increased speeds in cotton drawing processes [1, 5]. Since drawing is about the lowest cost-per-pound operation in cotton yarn manufacturing, considering both overhead and labor [13], and embodies one of the smallest capital investments per pound delivered [2], is it not logical to ask why this interest in increased production has arisen?

It can well be assumed that mills whose old drawing equipment must be replaced would seek the modern-type frames with highest productions possible. Similarly, mills anticipating an expansion, either in additions to present mills or the building of new mills, would seek the most efficient equipment available. Both of these needs are readily apparent and naturally would engender interest. Not so apparent, however, is the need for additional production in the card room to match increased productions in the roving and spinning processes, largely the result of improved machinery in these departments and the advent of high draft spinning. Lastly, the highly competitive markets experienced for the past five years, both foreign and domestic, have made it necessary to attempt increases in production without increased unit costs or significant losses, and preferably improvements, in yarn quality.

[1] President of the Institute of Textile Technology.

What do we mean by high production speeds in drawing? A survey [3] of several print cloth mills in 1952 showed drawing delivery speeds ranging from 61 ft./min. at the calender roll to 151 ft./min. As interpreted in the presentations today, high speed drawing refers to calender roll delivery speeds of 200–400 ft./min.

In investigation of increased speeds and frames developed for such speeds, what items must be examined in arriving at an intelligent decision to increase drawing frame speeds? Basically, one must consider all of the angles:

1. Granting that delivery speeds, and presumably production, can be increased in the order of two or three hundred percent, what is the cost per delivery as well as the possible amortization?
2. What floor space will be required?
3. How will maintenance costs be affected?
4. What will be the effect on day-to-day operations in the card room, such as work assignments?
5. How will sliver quality be affected?
6. Finally, what influence will increased speeds in drawing have on subsequent processes, both in regard to operational difficulties and the quality of products?

Assuming that new equipment is priced to meet market demands, can be amortized realistically, and will meet available floor space allotments, let us examine the remaining questions in some detail.

Effect of Increased Speeds on Maintenance Costs

Doubling or tripling delivery speeds should show a corresponding decrease in costs per pound of sliver delivered. Consideration must be given, however, to changes in repair and maintenance costs which might be experienced. Has the frame been designed mechanically to withstand such high speeds operating almost continuously for a long period of time? If not, high repair costs and maintenance may be the result. Even with durable equipment, changes must undoubtedly be made in the maintenance schedule. What are the parts most susceptible to degradation as a result of the high speeds?

First, the sensitivity of stop motion devices must be altered. At high speeds, the occurrence of a broken card sliver being fed to the frame must be detected rapidly, and correction must be taken before too much stock has flowed into the drafting rolls. Means for detecting lap-ups on the rollers must also be considered, for at higher speeds, two to three times more stock will be wrapping around the roll compared to present experience. A broken sliver in the coiler head will cause a great deal more stock to collect at the choking point. Stop motions for such breaks must therefore be examined meticulously. The maintenance of such stop-motions must also be considered.

It is also reasonable to question if more slivers can be expected to break behind the frame or during the coiling as a result of the increased speeds. An increase in the number of lap-ups would more than increase the time required at present for fixing these troubles.

And what of packaging? New demands will be made on the coiling apparatus, and changes must undoubtedly be made to accommodate the increased stock rapidly. A full can will be delivered in a shorter period, thereby requiring an increase in the number of doffs and time lost as a result of doffing during a normal eight hour day. Allowance must be made for these two events in calculating true production increase. A more intricate coiling mechanism may also require more careful maintenance and increased repair costs.

It can ultimately be expected that drafting rolls of the present types would not last as long when operating at drastically increased speeds so what will be the life expectancy of these rolls and roller bearings as compared to that experienced at present drawing speeds?

Finally, what increases in power consumption can be anticipated? With no improvements in methods for driving rolls, present power costs may be increased proportional to the increase in speed.

Effect of Increased Speeds on Operational Costs

It is not inconceivable that work assignments must probably be altered if higher drawing speeds are adopted. Increases in the number of doffs and production lost during doffing can be expected. If an increase in breaks before and after drafting is likely, the work assignment must be further increased. An increase in roller lap-ups would definitely result in more time lost for correcting this defect.

But what attention must be given to changes in the cleaning responsibilities of the frame tender? If the amount of stock processed in a regular shift is increased, an increase in the total amount of fly in such a period can be anticipated. It is also possible that higher operating speeds would cause an even greater increase in the amount of fibers resulting as fly. Both factors would increase work assignments, and allowance must be made for such possibilities in anticipating changes in labor costs.

If increased machine attention is necessary in the form of increased repairs and replacements or maintenance of settings, the present maintenance schedule must be extended. Such a step would also result in an increase of labor costs.

Effect of Increased Speeds on Quality of Sliver

Now that yarn manufacturing processes have been shortened to include only two processes of drawing (and often only one), one roving process, and single-creeled spinning, we can no longer rely on subsequent doubling to cover up the variations introduced at carding and drawing. Small variations in drawing sliver may be further amplified in roving and spinning processes [6, 9, 11] to become long-term variations in yarn.

In general, we know from Peacock's work in 1938 at the Georgia School of Technology [12] that when drawing speeds are increased from 65 to 140 ft./min., some increase in the tensile strength of the yarn was observed. The effects of very high speeds, such as 200–400 ft./min., however, have not been described in the literature.

What elements of the drawing frame will contribute to sliver quality? Doublings, the type of drafting system, draft distribution, roll types and diameters, tension draft, roll weightings, packaging—all of these

could play a part in the quality of sliver obtained.

When Arkwright [7, 14] had developed his card commercially and had seen his water frame adopted for spinning processes and his lantern frame used for the roving process, he recognized that card sliver contained a lot of fibers which were random in orientation. How else could the web support itself in carding? In addition, the average weight of the sliver varied from card to card. He then introduced the concept of drawing which included doubling to reduce uneveniness and drafting to parallel the fibers. Today we know that the long-term variations, i.e., yard-to-yard and longer, obey the statistical laws for doubling [4]. Specifically, if six doublings are used with a draft of six, the variation of six yard lengths of breaker sliver is reduced by the square root of the six doublings as compared to the variation of yard-to-yard lengths fed. Mathematically,

$$\frac{V_{\text{output}}}{(6\text{ yd.})} = \frac{V_{\text{input (1 yd.)}}}{\sqrt{6}(\text{doublings})}$$

Short-term variations, i.e., inch-to-inch, have not been shown to follow this law, presumably as a result of imperfect mechanical drafting.

How many doublings are therefore used, and why?

One finds a large number of drafting systems available for drawing: 2 rolls over 2 rolls, 2 over 3, 3 over 3, 4 over 4, 4 over 5, 5 over 5. Which system gives the best quality, or are all equally advantageous for good quality? In addition, are all systems equal in durability?

Similarly, one may select metallic rolls, covered rolls, or combinations. Are there special merits for either group?

As to draft distribution, the new Platt frame embodies the recommendations of the Shirley Institute for a low tension draft in the middle zone with most of the draft coming in the front zone. In spinning systems, a low break draft is commonly used. We should therefore examine the choice of draft distribution, particularly in terms of quality.

Roll weightings are also important. Excessive weights cause high power consumption and possibly fiber damage. Insufficient weights result in ineffective or no drafting. In between these extremes lie optimums from quality and cost considerations. How the weights are selected, in terms of total weight on all rolls and weights for individual rolls, and bearing in mind the interactions possible between rolls, should be carefully examined.

Coiling in the can should be accomplished efficiently in regards to the volume per can with a minimum of stoppage for broken slivers and for doffing. Yet, the quality of the sliver must also be maintained with little or no increase in weight variation because of poor control over the tension draft to the calender rolls and the cross-over of sliver coiled in the can.

Morton and Yen [10] have pointed to the presence of hooked fibers in card sliver and the partial removal of such hooked ends by drawing processes. We might also ask if any improvement in the removal of such hooks occurs as a result of high speeds.

Effect of Increased Speeds Upon Subsequent Processing

If the short-term variations of the sliver can be expected to be amplified in roving and spinning processes, we must be concerned with the ultimate effect of increased drawing speeds. First, can speeds be increased for both drawing processes? In fact, are two processes of drawing still necessary for best yarn quality? When processed into roving, does the sliver made with high drawing speeds have any greater or lesser tendencies to "break back"? Are ends-down in roving affected? And what of roving quality?

Our final judgment must be in regard to the spinning process and yarn quality. Small deficiencies in sliver are magnified during the roving and spinning processes. One must then determine if ends-down, roving "break backs," yarn quality, and spinning fly are affected when speeds are increased in drawing. Yarn qualities more long-term in nature should be especially tested—such properties as variation of skein weights, single-end strengths, long-term evenness, break factor, and skein strength. Average values may remain equal, but the variations about these levels may be much more significant. Since Loveless [8] has shown an increase in neps contained in yarns produced with several drawing processes, the number of imperfections in yarns made from sliver processed at high speeds should be carefully studied.

In Conclusion

Thus far, an effort has been made to cite those factors which should be considered in adopting high drawing speeds on present equipment or in the purchase of new equipment designed for such speeds. It is possible that present knowledge will not permit clarification on some of these factors. Nevertheless, our effort here has been to tabulate all possible factors to serve as a check list.

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High Production with the Whitin Even-Draft Draw Frame

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WE at Whitin feel that the new Whitin Even-Draft draw frame, Model M, will prove to be one of the most outstanding and salable machines that Whitin has ever put on the textile machinery market. My purpose at the Cotton Clinic was to explain, first, the history and groundwork that went into our conceiving the idea for the Even-Draft draw frame, second, some of the major factors in its design and manufacture, and third, our experience to date with this frame in various textile mills.

To go back a few years in the history of draw frames, Whitin's 1890 catalog, some 66 years ago, showed a frame equipped with 4-roll drafting and leather-covered top rolls. The diameter of the front roll was 1⅜ in. while the other bottom rolls were 1⅛ in. This draw frame was equipped with front and back stop motions, a weight relieving and equalizing motion, and the traditional type of drive, using a bottom countershaft to a tight and loose pulley with a leather belt for the drive to each individual head. The production rate was based on a speed of about 100 ft./min. It is very easy to see that this frame, while looking quite old-fashioned, was not very different from draw frames built throughout the world right up until the present day.

From the mill man's point of view, drawing has improved tremendously since 1890. Machinery manufacturers have been able to build draw frames to much closer tolerances, allowing evener sliver; to improve components of the frame, such as stop motions, which make for more positive and trouble free operation; and finally, to build frames for the use of larger cans, permitting higher efficiencies. Nevertheless, over the years, progress had been relatively slow.

At Whitin this problem has been given serious consideration for some time, and the first step leading to

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the eventual design of the Even-Draft draw frame was taken in January 1953. At that time, it was planned to design a frame with a production rate of between 175 and 200 ft./min., electrical stop motions, gyrating no-twist cantable, accommodation for 14- and 15-in. cans; and to incorporate every development that was felt would make for a flexible and efficient machine. The result of this work was the Model L3 draw frame which was exhibited at the American Textile Machinery Exhibition at Atlantic City in April 1954.

This Model L3 ran at 200 ft./min. It was equipped with an electrical clutch drive, special gearing, extended sliver table and lifting rolls, spring weighting under the roller beam, and special electric stop motions.

The Model L3 was quite a success at Atlantic City and a number of orders were received for it. However, after the exhibition, taking into consideration our experience up till then with the frame and the comments of the many mill friends who had inspected it, the consensus of opinion was that we were not completely satisfied with the performance of the L3. This was due to two major problems: first, certain mechanical difficulties experienced by trying to run a conventionally designed and built frame at 200 ft./min., and second, the purely textile problem of trying to cope with the lint and fly engendered by these high speeds. This latter problem was particularly serious. It was felt that if we were to design a frame that would be efficient in the mills on all types and qualities of cotton and synthetics, a new solution must be found to the clearer problem. In short, we did not feel that any conventional approach would permit these high speeds and still maintain both the desired quality and efficiency.

After discussion of these two general problems, it was decided that the only solution was to design a completely new draw frame from the ground up; this design became our Model M Even-Draft. The goal was to streamline the machine as much as possible in order to facilitate cleaning and improve the appearance; to incorporate the 4 over 5 drafting arrangement with possible drafts of 4 to 10, and make the machine suitable for stock from $\frac{7}{8}$ in. to 3 in. in length; to have a separate motor drive for each four deliveries so that any complicated clutch drive could be eliminated; to use our patented no-twist cantable; and to build the most rugged and precise machine possible to permit continuous high speed operation.

After consideration of different types of clearers, such as the Ermen clearer, and synthetic clearers that work the short waste back into the stock, it was decided that the only practical solution would be to undertake the development of suction air clearers in cooperation with the Pneumafil Corporation. While this latter development was not without difficulties, I am sure that the Even-Draft draw frame would not be a success today with any other type than the simplified suction air clearers we now use.

This concludes the past history of this Model M Even-Draft draw frame and brings us to the machine itself. Basically, it is an extremely rugged two-head eight-delivery machine equipped with suction clearers for the top and bottom rolls of the 4 over 5 drafting system and designed from the ground up for high speeds and low variation year after year. A large majority of the components have been tested for several years on other machines, such as the Roto-Drafter, and by many thousands of hours of mill operation. Now to discuss some of the more important features. These will be divided first into those which are structural and apply directly to the mechanical design; second, to features which apply directly to the textile processing of the drawing sliver; and third, to those that contribute to the efficiency of the operator running these frames.

Structural Features

First in importance is the beam of the machine. This is the foundation of the machine and is responsible for allowing us to build with the precision that we achieve. The beam is a massively constructed section, ribbed throughout for extra rigidity. It weighs a thousand pounds, is thoroughly stress-relieved before machining, and is held to a flatness tolerance of 0.001 in. over its entire surface. Furthermore, the sides and ends are held square to a tolerance of 0.002 in.

The next structural feature is the roll stand. This again is a massive piece of cast iron, normalized to permit accurate machining. The height of this stand is held to 0.001 in., and the bearing centers to 0.002 in.

Next, the bearings. Perhaps the most important of these are the extra heavy duty antifriction bearings used on the 2-in. front bottom roll and 1-in. second bottom roll. These same bearings have given several years of trouble-free operation on the Roto-Drafter where total roll pressures run as high as 800 to 1,000 lb. While on the subject of antifriction bearings, it is perhaps interesting to note that there are 152 in this machine, a major factor in smooth run-

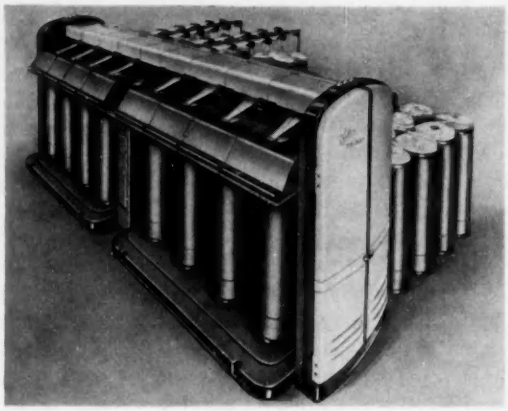

Fig. 1. Front view, Even-Draft draw frame.

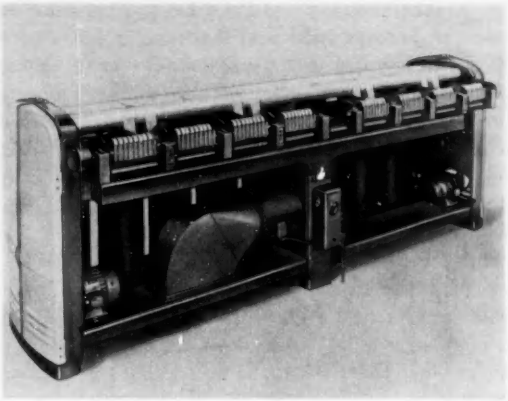

Fig. 2. Rear view Whitin Even-Draft draw frame, showing Pneuma Clear ducting and heavy frame construction.

ning and long life. The back roll bearings are plain with grease lubrication, but are constructed of a special iron that is extremely resistant to wear, and are bored to within 0.001 in.

Of course the rolls are really the heart of this machine and we employ a special high carbon steel, hardening the rolls to the same hardness required by ball bearing manufacturers for their raceways.

As to the gearing, access to all gears is gained by opening the head end door. We think that the Shirley Institute in England was correct in pointing out, some years ago, that the conventional draw frame method of driving down the front roll to another train of gearing to drive the back rolls causes excessive torque in the front roll, which in turn produces vibrations in the roll and increases the unevenness of the sliver produced. In this draw frame all rolls are driven from the head end, in other words, each four deliveries of the frame has its own head end to drive the rolls from one side only. Helical cut gears are used for the high speed tension gearing and all studs are either antifriction or are lubricated directly from our Bijur centralized lubrication pump. All roll gearing is hardened steel and cut to extremely close tolerances. An antifriction coiler gear of Whitin's own design will be standard on this frame. Commercial bearings proved unsatisfactory and too expensive, so it was necessary to start from scratch to build the complete unit ourselves. This will also be lubricated from the Bijur system.

Textile Processing Features

Considering the textile features of the Even-Draft draw frame, the most important is the 4 over 5 drafting system. In 1953 and 1954, a very carefully controlled and, in fact, quite lengthy test was run on virtually every major arrangement of draw-frame drafting. Among those tested at that time were 4-roll conventional, 4-roll conventional with the Shirley Institute's method of draft distribution, 3 over 4 drawing, 2 over 2 drawing, as advertised abroad, 2 over 3 drawing, and finally, our unique system of 4 over 5 drafting. On all these types of drafting systems were run a wide variety of stock, processing among others $\frac{7}{8}$-in. and $1\frac{1}{16}$-in. carded cotton, $1\frac{5}{32}$-in. and $1\frac{9}{16}$-in. combed cotton, $2\frac{1}{2}$-in. viscose and wool blends, and $2\frac{1}{2}$-in. Dacron. I was looking over this test again in preparing this paper and was struck once more by the significant superiority that was shown by the Whitin 4 over 5 drafting system.

To describe the 4 over 5 drafting system, I will take the liberty of quoting the very excellent presentation of our Carl Brandt before the Southern Section of A.S.M.E. as follows:

"The five bottom rolls from front to back are in order 2 in., 1 in., $\frac{3}{4}$ in., $1\frac{3}{8}$ in., and $1\frac{3}{8}$ in. in diameter. With the exception of the $\frac{3}{4}$-in. roll, all are regular fluted rolls. The four top rolls are all $1\frac{5}{8}$ in. in diameter, covered with a standard synthetic. The only roll setting requiring any degree of care is the distance between the second and third bottom rolls. Rolls 1 and 2 are fixed, and so also are 3 and 4. The only adjustments are between 2 and 3 and 4 and 5. Since practically all of the drafting takes place between 2 and 3, this is the only point which requires close setting according to staple length. A break draft must be used at times in the

back section, therefore provisions have been made to run drafts up to 1.5 at this point. Naturally, when a break draft is used, this back section must also be set to the length of staple. All roll adjustments are made from above the stand so it is no longer necessary to work from underneath, a position that is always very awkward and unsatisfactory.

"Top roll #2 has two points of support, on the 2-in. bottom front roll and the 1-in. second roll. The effective gripping point is where it contacts the 1-in. roll, and since most of the work is done at this point, adequate pressure must be provided. To guarantee this, 200 lb. are applied here. Part of this load is carried by the front roll; so you have in effect a double grip on the stock and any deflection of the 1-in. second roll is prevented.

"Top roll #3 also serves a dual purpose. Where it contacts the 1⅜-in. roll, it forms a positive bite and control point while fibers can be pulled between the roll #3 and the ¾-in. roll without breaking them. No spacers of any type are used since it was found that by locating the top roll bearing slide in the proper manner, contact can be held even when the top roll diameter is changed as happens at time of buffing. This arrangement, when adjusted to minimum distance, places all fibers longer than ⅞ in. under control. While the rolls 2 and 3 are spaced at maximum spread, a staple of 3 in. length is nicely accommodated."

Another important textile feature is the suction clearing system built into this frame. As mentioned earlier, we feel that to achieve high quality work at

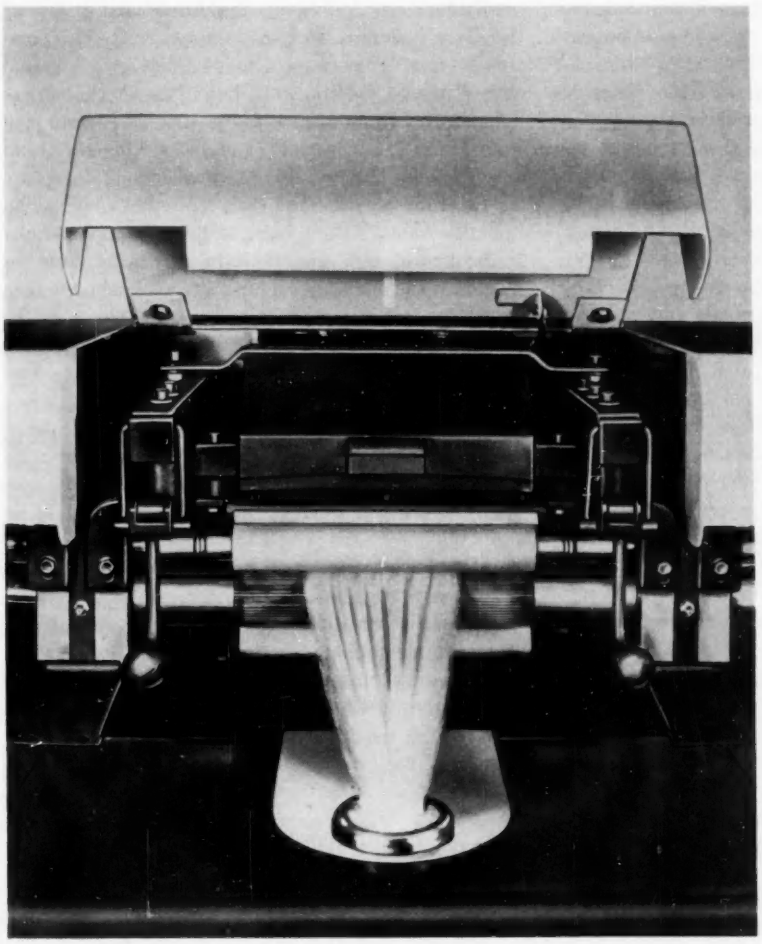

Fig. 3. Roll weighting and Pneumafil, Even-Draft draw frame.

the high speeds of 250 to 300 ft./min. that are being run with this frame, no other clearer arrangement would be satisfactory. Lint and fly are bound to increase as speeds are increased and, in particular, the control of the accumulation becomes more and more difficult. It is believed that this frame would not be a success without the suction clearing system.

Furthermore, we are sure that there will be certain other advantages to its use, many of which cannot be directly calculated. The waste carried off by the suction air clearers appears to be very short and its removal at this point will be a help to subsequent operations. It is interesting to note that in one mill, where a sample frame has been in operation for some time, spun yarn from the sliver from the Even-Draft frame has been knitted by an independent laboratory. This mill superintendent was encouraged to learn from the laboratory that the knitting of this stock had gone exceptionally well, without a single gout appearing to jam in the needles. One of the reasons for building this frame in only two heads of four deliveries was to place the suction clearer arrangement in the center leg. This helps amortize the cost of the fan, motor, and collection box over as many deliveries as possible; to keep the collection equipment within the actual dimensions of the frame itself; and also to ensure an even suction to all deliveries.

A further textile feature is the no-twist cantable which Whitin patented some years ago and has been using with great success on other of its machines. This cantable gyrates instead of revolving, and hence coils the sliver with absolutely no twist. Careful tests by independent researchers have shown that this lack of twist in the coiled stock will in turn lead to improved evenness in the subsequent processing.

This no-twist cantable is driven by a chain drive with Bijur lubrication to the sprockets. This permits the changeover from 36-in. high to 42-in. high cans to be made in the mill with a minimum of work. All that is necessary is the purchase of raising blocks for each head end and the center leg and a longer chain for the cantable drive.

Improvement of Drawing Efficiency

Now as to features which materially increase drawing efficiency. First is the accessibility of all parts. All electrical equipment is enclosed in a separate cabinet in the head end and is thereby readily accessible to the mill electrician.

The second point is the overarm weighting, permitting the complete elimination of weight hooks and weights underneath the frame, together with complicated weight-relieving motions. All rolls are weighted directly by special precalibrated springs held in the top arm and easily adjustable for the third and fourth top rolls. Weight is applied by the small lever working through a toggle latch, and should an operator forget to apply the weight to one delivery, this is readily seen by the position of the weight levers which move to an almost horizontal position.

It is believed that with our design of front and back stop motions, together with the very low voltage circuitry used, we are contributing tremendously to efficient operation. These stop motions operate through an electronic tube at a 6-volt potential, eliminating all possibility of shocks and arcing. Furthermore, when piecing in a broken sliver, it is only necessary to lay it through the sliver guide into the back sliver pan. Jogging the frame will then run the sliver under its back stop motion roll. The front stop motion operates on a toggle joint principle and moves in two directions. Should the stock become light at the front of the frame due to a front roll lap-up, the two calender rolls close together and make contact. Should there be a calender roll lap-up, the two rolls separate and once more make contact to stop the frame. Both back and front stop motions are hooked up to a separate light at each head end in order that the operator may quickly ascertain whether the reason for the stop is behind the frame or in front. A third light is also provided in the center position to indicate when the predetermining counter has shut off the frame for a full can. This latter feature should be of considerable help, particularly to those mills where block creeling is employed.

Other items might be mentioned, such as the use of a can creel behind the frame to allow for the use of larger diameter cans which are daily becoming more prevalent in the industry and the Bijur oiling system and grease fittings used to permit centralized lubrication of the frame, or as is the case with the grease fittings on the roll stands, lubrication at long intervals. However, in general, I think that our best contribution to mill efficiency with the Even-Draft draw frame is the combination of all these factors in a streamlined design which not only facilitates cleaning, but also adds to the appearance of the mill's card room.

In reporting our mill experience with the Model M Even-Draft draw frame, I would like to make one point clear. The figures given here are, we feel, those that can be expected in use over a long period of

time. These are not the result of lucky tests under carefully controlled laboratory conditions, but in large part are from the experience of mills where the draw frame has been in use, run by the mill's employees over periods of time ranging up to several months.

A question that will come up, and one for that matter which has already been asked, is whether or not the high speeds utilized in this frame have a detrimental effect on the evenness of the finisher drawing sliver. Tests in Whitinsville and in the mills show that there is no change in variation with this frame, whether the speed be 100 ft./min. or 300 ft./min. In short, on a carefully designed draw frame, variation is not a function of speed.

Sliver variation varies widely from mill to mill due to different cottons and different mill practice in the preparatory processes. Furthermore, everyone is familiar with the wide variance experienced from tester to tester. Nevertheless, typical figures of a several weeks' test in a southern mill on 1⅛-in. carded work show slightly below 14% on the Uster tester. Another southern mill's average of 24 tests on 1 1/16-in. carded cotton was 13.5% on the Uster tester. A southern combed yarn mill found that after two processes, 1⅛-in. combed sliver came down to about 10% on the Uster tester.

More data could be given but it can best be summarized with the general statement that we expect Uster average variation on carded work to be in the range of 12 to 15%, with the majority of the work run approaching 13%, and on combed work to be in the range of 10 to 12%. It would appear that these figures represent what may be expected in good running mills with average maintenance and scouring schedules.

As far as efficiency is concerned, we are basing our estimates on one mill in particular where the Even-Draft has been run for over three months. Here the mill's employees are running this frame 24 hr. a day and achieving efficiencies of 80 to 88% at 300 ft./min. Furthermore, this particular frame has not had applied to it as yet the latest improvements to the suction clearing system nor the three signal lights on each head end, features which it is thought will improve the efficiency even further.

One item should be mentioned, namely, the size of cans utilized. It is our opinion that the efficiency achieved will be very much a function of the size of the can, particularly the can in the back of the frame. With no more picking of clearers and with the general cleaning loads reduced considerably, practically all of the operator's time will be spent in either doffing or replacing empty cans in the creel. We recommend a minimum of the 14-in., and would prefer the larger 15- and 16-in. cans now coming into use, all of which can be utilized by this frame, both in the 36-in. and 42-in. high sizes. A 16 × 36-in. can can be filled with 28 to 30 lb. on carded work and 30 to 32 lb. on combed work.

Production can be easily varied, using the varipitch sheave furnished as standard. This allows the frame to be set at any speed between 240 and 300 ft./min. Typical productions producing a 60-grains/yd carded finisher drawing sliver at 300 ft./min. would give 41.2 lb. per delivery per hour at 80% efficiency of 330 lb. per frame hour. A 55-grains/yd. sliver, again at 300 ft./min. and 80% efficiency, permits a production of 37.6 lb. per delivery per hour. A very fine quality combed mill running a 50-grains/yd. finisher drawing sliver at 275 ft./min. would achieve 31.5 lb./hr. per delivery at 80%. As mentioned previously, we feel that these figures may be bettered, but we believe that 80% efficiency is a conservative figure, based on our expectations of one operator being able to run four frames.

In this talk, I hope that I have been able to give a bit of the story on our Model M Even-Draft draw frame. I also hope that I have been able to not only illustrate some of the technical details of this frame, but also to explain the processes of the research thinking and the time and effort that went into its development. As will be seen, it has been a long and difficult research task, but we are now very confident of the results obtained and optimistic for the sales potential of the Even-Draft draw frame.

High Production with Metallic Rolls

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HIGH production with metallic rolls, incorporating several theories, was developed to meet a growing demand for improved drafting at the drawing frame process at higher speeds and longer drafts, with more doublings. This presentation is relative to the Feathertouch Drafting System, using metallic rolls with ball bearing journals for both bottom and top rolls. Both metallic and composition roll changeovers for conventional drawing frames were produced over a period of several years prior to this development, and it was determined through numerous tests that certain conditions existing in the old drafting systems were detrimental to proper drafting at higher speeds, such as vibration, heat, static, and design. Therefore, it was apparent that the old systems must be changed drastically.

To develop a system that would accomplish the ultimate in drafting, it was believed that metallic rolls offered the greatest possibility. If properly designed and arranged, they would last longer without repair, could be produced more accurately, would put a permanent crimp in the stock which would be beneficial, and would withstand the heat generated at high speed and longer drafts without injury to the rolls.

Theory and Design

Let us consider the theory and design of the new-type metallic drafting rolls. It was believed that all rolls of one size would draft any length or kind of staple, from the shortest staple through four inches, including blends. Rolls were designed, all of one size, for both bottom and top rolls, using an alloy steel that would be very hard when heat-treated, would resist static electric currents, and would have a smooth hard finish after grinding to very close tolerances so that the nicking and burring which caused lap-ups would be eliminated.

The flutes were designed to incorporate four different graduations, beginning with the finest graduation for the front line of rolls, and becoming progressively coarser for each line of rolls from front to back. The flutes were changed from a dimetrical pitch, 14½° pressure angle type to a form ground flute with approximately 8° side angle without a dimetrical pitch line. Also, a much longer flute was used to accommodate laps to avoid bunching or overlapping of slivers and to aid in maintaining more accurate alignment of flutes. This new-type flute (Figure 1) is much thinner at the meshing depth than conventional to permit stock to pass between bottom and top roll flutes while drafting at high speeds without undue pressure on the stock from the weighting system. With a web of stock weighing 60 grains/yd. between the flutes, we can rock the top roll backward and forward with the fingers approximately 0.025 in. without moving the bottom roll, even though the spacers, or collars, are held together firmly by the weighting system.

Journal Bearing Design

Vibration being one of the greatest handicaps to high speed drafting with metallic rolls, it was decided to develop journal bearings that would do several things: (*1*) eliminate high frequency vibration; (*2*) remove the revolving collars used to space the depth of flutes and drive top rolls; and (*3*) eliminate frequent lubrication that would surely multiply the chances of grease from conventional journals getting on the stock, due to the increased heat generated at higher speeds.

Prelubricated and sealed ball bearing journals for both bottom and top rolls were designed, using the outer journal housings as collars, or flute depth

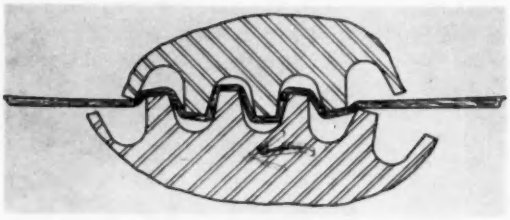

Fig. 1. End-view section of metallic drafting rolls. Shows how stock passes between new type flutes without damage.

spacers. These journal housings do not revolve, and this arrangement did away with revolving collars to drive top rolls, making it necessary to drive them with the bottom roll flutes through stock between the flutes while drafting. This method of driving top rolls is a vital phase of the new drafting system that will be explained in this paper.

Using the stationary bearing housings for regulating depth of flute mesh makes it possible to control flute meshing very accurately and maintain it indefinitely, as there is no wear from stationary spacing. It also removes all vibration from top rolls caused by revolving collars driving top rolls.

This arrangement of bottom and top roll journal bearings also removed pressure of the weighting system from bottom and top roll journals, because the weighting is supported by the journal bearing housings resting on slide stands. For instance, a 14-lb. weight can be hung on one end of a front top roll and a 100-lb. weight on the opposite end of the same roll, and the unbalanced weighting will not affect the tension. Also, the top roll can be rocked back and forth with the fingers when the frame is stopped. This is why the phrase "Feathertouch Drafting with Floating Top Rolls" is used, and this arrangement and design of flutes is the reason fibers are not damaged with this system. The floating top roll advantages are used only for the first and second lines of rolls from the delivery side of the frame because the stock, or web, has been drafted until it is very thin just prior to entering the second line of rolls.

The third and fourth lines of rolls are used to even out thick and thin places in the sliver entering the drafting system in the following manner (see Figure 2). The top roll on the fourth line of rolls rides the stock and will not damage fibers, due to the mass being thick, and the instant the mass of slivers passing through these rolls increases in thickness, the top roll raises up, decreasing the depth of flute mesh of the bottom and top rolls. In turn, this decreases the effective diameter of the rolls, and a shorter length of stock passes between these rolls, thereby increasing the draft between the third and fourth line of rolls, removing the increased thickness of the stock. By the same method, except in reverse, if a thin section of stock enters the back rolls, the top roll will move downward and increase the meshing depth and effective diameter of these rolls, causing a greater length of stock to enter the drafting zone between the third and fourth rolls. This will decrease the draft in this zone and will heavy up on the thin place by not drafting this section as much as an average thickness web. This evening effect improves long- and short-term variation by removing short spaces of light sliver, as well as heavy places; it works the same way on any length of varying weights because it works immediately and continuously, causing the fourth roll to become a metering roll. To get the best results from the above condition, the stock mass entering the fourth roll must be regulated to the same width on all deliveries, and it will not operate properly with lifting rolls or laps that present a constant amount of stock to the fourth roll.

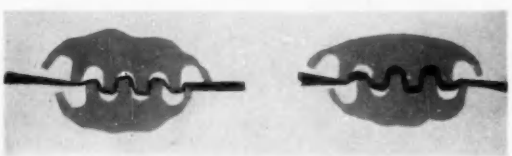

Fig. 2. Front and back roll sectional views.

The most effective weighting for this drafting system, determined after much testing, is dead weighting arranged as follows, beginning at the front: 14 lb. for each top roll journal of the number one line of rolls, 14 lb. for the second line, 16 lb. for the third line, and 18 lb. for the fourth line of rolls. All weights should be within 3 oz. of designated pounds. This applies to 6, 8, or 10 ends can creel drawing, producing sliver from 40 grains through 75 grains/yd.

Inner draft distributions, or break drafts, were determined through hundreds of tests. For all kinds of staple, blends, and amounts of draft, the formula is as follows: the square root of the total draft is the desired draft between the first and second rolls, and the draft between the third and fourth rolls should be the square root of 2½% of the total draft, plus a draft of one. This formula also regulates the draft between the second and third rolls. These drafts are for four lines of rolls, and do not apply to comber preparation or five-roll drawing.

Control of varying fiber lengths is accomplished by the crimp put in the stock by the special design of flutes and the floating top roll arrangement. These crimped places at very short intervals are very noticeable on all staples of ½ in. and longer, and a large percentage of staples down to ⅛ in. have this crimp. It is believed that while the fibers are bent around both bottom and top roll flutes, a slight pressure is placed on them by the bottom roll flutes while the top roll is being driven; this is the method of energizing the top roll, and at the same time the increased

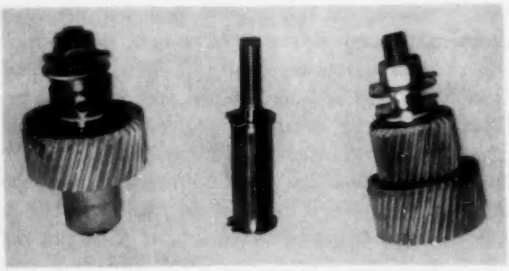

Fig. 3. Prelubricated and sealed ball bearing gear studs permit of high speeds.

resistance of the fibers to drafting at high speed is considerable. The pull on fibers at the time they are bent around the flutes, plus pressure of the bottom roll flutes against the top roll to revolve it, is similar to folding a piece of paper over the edge of a table and applying pressure with the fingers to set the bend. This crimp in practically all fibers causes the shorter ones to adhere more readily to the longer ones and travel through the drafting zones more consistently. Also, the crimp left in the web by the front roll is of great importance on all stock, especially combed stock and light sliver, while it is being removed from cans at the next process. This crimp almost eliminates from the slivers splitbacks which cause a thin place and double back, causing a thick place; and helps to keep stock from marrying or sticking together. Several feet more sliver with crimp can be pulled from cans before separation than sliver without this crimp.

Gearing and Stud Development

Roll and journal bearing designs completed, the next step was gearing and gear stud development. Since there was extreme difficulty with all metallic gearing and conventional studs heating up at high speeds, it was decided to replace plain studs with prelubricated and sealed ball bearing studs (Figure 3), and replace every other metallic gear with phenolic, or fiber, gears. Ball bearing gear studs with this gearing would permit closer setting without heating up as readily as all metallic gearing. Studs would require no oiling, and gearing would require very little oil. This setup would permit meshing of gears without backlash between any two bottom drafting rolls or the entire group.

A drafting system without any backlash in drafting rolls is of great importance in 300 to 400 ft./min. or greater production on this system with free turning bottom rolls and floating top rolls. This is due to the increase and decrease of resistance at short intervals while drafting, caused by the inconsistency of fineness or denier, varying staple lengths, oiling or chemical treatment of stock prior to carding, humidity, and parallelization of slivers prepared for the drawing frame process.

This drafting system was first developed to make changeovers on existing drawing frames to operate at approximately 200 ft./min., because it was believed generally by the mill operators that successful drafting limits were about 125 ft./min. and because it was known that existing coiler systems would not

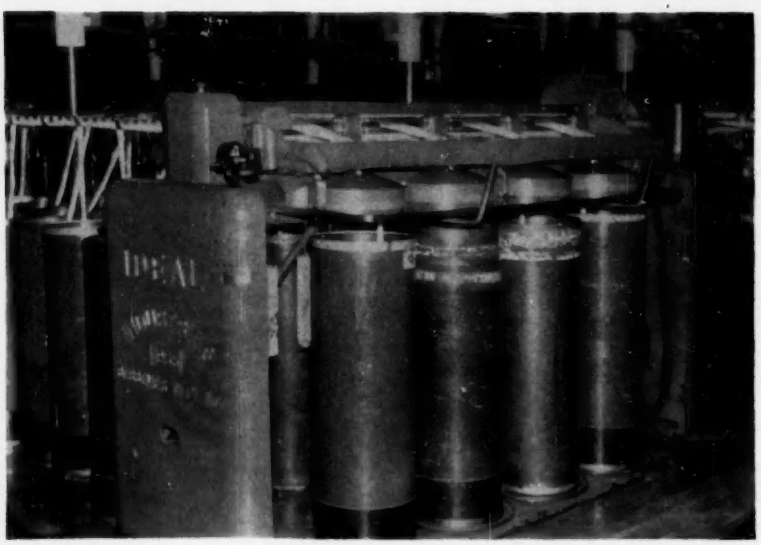

Fig. 4. Ideal Industries new drawing frame with ball bearing coiling systems.

operate efficiently above 200 ft./min. After these changeovers had been in operation for some time and requests for higher production and larger cans increased, it was decided that an improved coiling system must be developed to operate at higher speeds. The new coiler was designed so that the tube gears and drive gears would be supported by ball bearings and would not ride on the coiler plate. This arrangement would not require any grease to relieve the friction causing excessive heat and noise between the coiler and coiler plate. The coiler plate and face of the coiler were made of fiber to relieve further heat caused by friction of sliver as the can is being packed and to help relieve static buildup that is present with metallic coilers at higher speeds.

During this time ball bearings were developed for the remaining shafts, journals, and pulleys. Knock-off motions were revamped. Pulleys, shafts, and drives were balanced to help eliminate vibration.

Feathertouch Drafting System changeovers running from 125 ft. through 250 ft./min. for over four years helped to overcome a belief that successful drafting could not be done at greater speeds. However, tests during this time by individuals, laboratories, and technical institutes at over 400 ft./min. proved that this drafting system would go far beyond limitations of changeovers. This meant that a frame must be built that would incorporate all improvements, including some that were being tested, some in development, and some yet in the designing stage, if drafting at 350 to 500 ft./min. was to be generally used. A more rigid drawing frame was developed, incorporating all improvements at that time (Figure 4). Installations were made, and results are gratifying. Maximum speed of the Feathertouch Drafting System is unknown if properly surrounded by other necessary adaptations for ultra high-speed drafting.

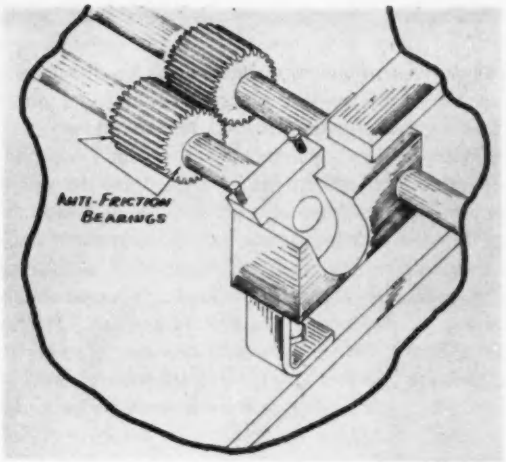

Fig. 6. Fluted calender rolls employed to increase crimp in sliver.

Improvements under Consideration

1. High humidity, or damp coiling, with either chemically treated or just plain water, to increase the yards per can on cards, drawing frames, and

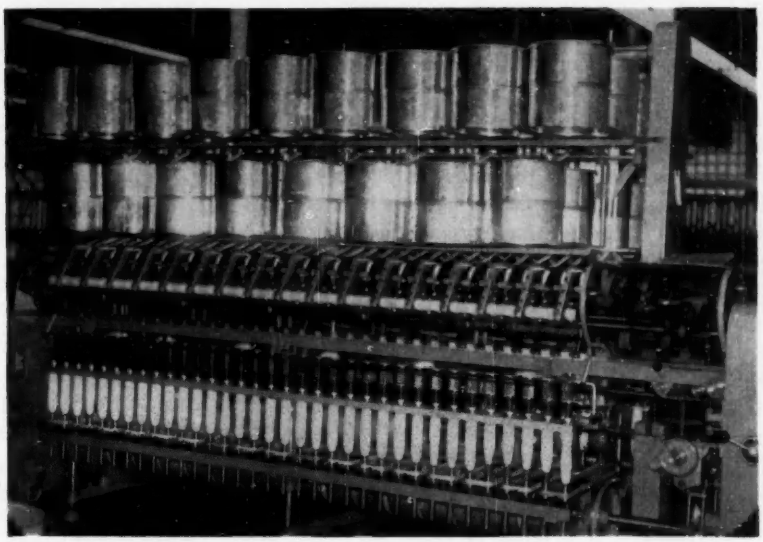

Fig. 5. Direct spinning frame sliver produced on Ideal Industries new drawing frame.

roving frames, with coilers using small cans to be used on spinning frames. This same coiler system can be used on drawing frames to coil for direct spinning (Figure 5). We believe that direct spinning offers a great possibility to the textile industry, and eventually flyers will be discontinued. The advantages of wet coiling will also eliminate the necessity for high compression calender rolls to reduce the size of sliver which causes a hard core in some stock that is difficult to draft out properly. Replacing flyers with coilers on roving frames can tremendously increase the production of these frames.

2. Fluted calender rolls for cards and drawing to increase the crimp in sliver, using the same method of floating top roll as the drafting system (Figure 6). This will remove the pressure from stock now necessary to pull same through the trumpet with conventional calender rolls, and will increase the strength of the sliver for removing from cans, as well as other advantages mentioned previously. It has an adjusting feature that will permit running different size sliver or roving at each coiler head, if desired.

3. Additional improved evening of stock entering drawing, roving, and spinning to improve long- and short-term variation. In turn, this will help to reduce variation in numbers.

4. Improved control of waste that removes usable fibers from stock. At the same time, this will reduce the amount of cleaning necessary at present for quality work.

Saco-Lowell Versa-Matic Drawing

Robert M. Jones[1]

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IN describing the new Saco-Lowell Versa-Matic drawing frame, the drafting element will not be emphasized. This was described in some detail in a previous talk, before the A.S.M.E. in Atlanta last fall, and for those who are interested, there are copies available.

The Versa-Matic drawing frame employs the Shaw principle of a large middle roll that rests firmly on the third bottom roll and is held in close proximity to the second bottom roll. The slivers are fed into the back pair of rolls with suitable guides, as is customary. There they receive a small tension draft to orientate the slivers and tension all of the fibers. Without these tension and straightening zones, careless piecings, crossed slivers, and unparallel fibers are not properly drafted out. As they approach the bite, or nip, of the large middle top roll and third bottom roll, the leading ends of the fibers are rubbed and groomed by the arcuate surface of the third bottom roll. The middle top roll rests firmly on the third bottom roll, with a positive bite or nip at point A-A. This same middle top roll is prevented from resting on the second bottom roll at point B-B by collars which establish a predetermined space between these rolls at this point. The slivers are then given their major draft between the nip of this middle top roll and the nip of the front pair of rolls; but unlike the action with positive drafting rolls, the floating fibers are restrained from going forward out of sequence by the soft nip and snubbing effect of the second bottom roll and middle top roll. This action is similar to the restraining influence of the fingers and thumb exercised by hand spinning, as shown by the dotted lines in Figure 1, and because of the true slip draft principle employed, produces sliver of excellent average uniformity with less variation spread than any other system tested in our laboratory.

In this paper will be outlined those mechanical features of this new frame which are believed to be essential to the continued production of first-grade drawing sliver over a long period of years and without which, insidious sliver deterioration sets in, resulting in costly yarn and fabric losses.

As has been pointed out in the preceding papers, it is not possible to modify existing drawing frames

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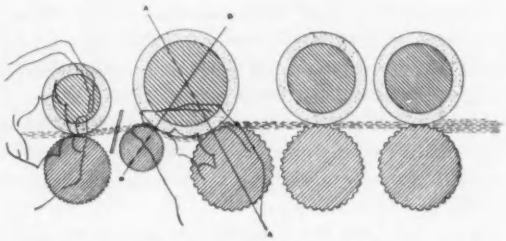


Fig. 1. Shaw principle of drawing. Illustrates rollers substituted for fingers and thumb.

so that they can produce first quality sliver at a high production rate, and package this sliver in large containers, without a complete rebuilding of the frame; and even when this is done, there are many elements and bearings that were not designed for high, sustained speeds, even if adequately lubricated, resulting in heat and wear and trouble.

Extensive studies have been made by the Shirley Institute and others which show the necessity of maintaining concentric rollers, and this concentricity must be held to closer tolerances for higher drafts than for low drafts. Also, any eccentricity of the roll produces variable, irregular velocities in the rolls, which in turn generate irregular drafting waves in the sliver. Equally important, but not nearly so obvious, it has been shown that worn intermediate gear bearings produce the same irregular drafting waves.

Previous to the advent of long draft spinning and long draft roving, many of these errors were partially overcome and hidden by the multiple doublings in roving and spinning. Today, with one-process roving, and yarn spun from single roving in the spinning frame, any variation in the drawing frame sliver is reproduced, attenuated and magnified, in the resultant yarn.

Therefore, it was recognized some years ago that a better and more efficient drawing frame must be produced, so a completely new machine was constructed by Saco-Lowell.

The following specifications were laid down:

1. It should be made in four delivery heads only, as more deliveries decrease efficiency.
2. Each head to be driven by an individual motor, with a built-in brake.
3. Electric stop motions throughout, with indicator lights.
4. Overarm spring weighting.
5. All rolls, top and bottom, mounted on anti-friction bearings.
6. The drafting element to be built around the proved Shaw principle with 3-over-4 or 4-over-5 rolls.
7. All gears in the drafting or calender trains to revolve on antifriction bearings.
8. Each bottom roll to be driven independently. No roll to be used as a shaft to drive another roll.
9. Despite provisions for close settings, all roll or intermediate gears to be kept relatively large to prevent chatter and to provide simple and correct adjustment.
10. The turntables to be provided with flanges centering the cans from the inside, making it unnecessary to lift the cans over a flange for doffing.
11. A creel for six or eight ends-up at the back or for lap back.
12. Provision for substitution of the regular calender rolls and tube gears by a Positube type of tube gear with built-in calender rolls when running man-made fibers or wools or mixtures prone to static trouble.
13. Provision for Twinstrand tube gears for split webs to provide individual coiling of the slivers when two slivers are placed in one can.
14. Automatic clearers that positively wipe every line of every roll.
15. Provision for lubrication that does not require daily oiling; if possible, once in six months or longer.
16. Rigid unit construction to ensure correct alignment and a minimum of maintenance.
17. Smooth exterior contours to reduce waste and fly accumulation and minimize cleaning operations.
18. Antifriction tube gears and high speed drive for same.

These specifications have been fulfilled as follows.

The Chassis

First, to attain maximum rigidity, strength, and freedom from breakage, steel is used for the beam and its supports. Steel has a modulus at least two and one-half times that of cast iron; therefore, the steel roller beam is stiffer and deflects less under load than the cast iron beams formerly used. This ensures positive horizontal alignment of rolls and gearing from the time of erection in the shop, when placed in service in the mill, and at all times thereafter, irrespective of the type or condition of the floor. Likewise, the head and foot end supports are made of steel, thus being practically unbreakable from the im-

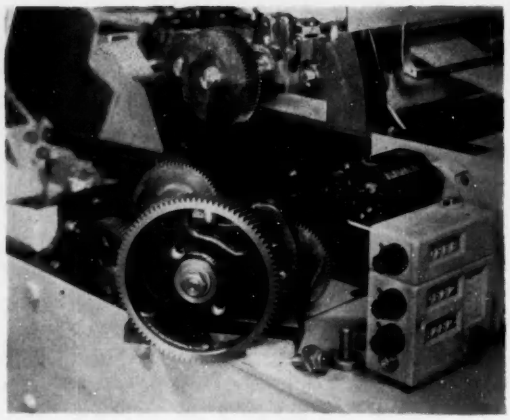


Fig. 2. Gear stand, Versa-Matic drawing frame. Can be removed from beam as a unit as shown. Electric yardage counter at right.

pact of trucks or other accidental causes such as moving or relocation. Furthermore, the painted steel plate lends itself to smooth lint-shedding exteriors, easily cleaned and maintained.

Gearing

To make certain that the gears are kept in alignment, heavy stands of unit construction are used. For assembly and overhauling, the stands can be removed from the beam as a unit, as shown in Figure 2.

Each bottom roll is driven independently, and at the same time all driven gears are relatively large. All the gears are easily accessible, and all idler gears are positioned in swing arms, thus facilitating adjustment, because only one pair of gears need be meshed. All mill men who have tried to set intermediate gears, mounted on free studs between two other gears, will appreciate this swing arm construction. All of this is made possible by the introduction of a large-diameter jack shaft running under the beam from the head to the foot end.

As can be seen from Figure 3, power from the electric motor is transmitted by two "V" belts to the 7-in. P.D. sheaves mounted on a common shaft with a 67T. helical gear. This 67T. gear is meshed with a 101T. gear on the head end front roll drive shaft mounted in ball bearings which are independent of the front roll. The front roll is driven through a nylon coupling mounted in line with this head end shaft, but cushioned from any vibrations of the gears themselves. Both the calender rolls and turntable are driven from this front head end shaft; the calender rolls by helical gears with large tension change gears (60–68T.).

The tube gears and coiler are in turn driven by a chain with different tooth sprockets for various diameters of cans and the lay of the sliver in the can. All high-speed intermediate gears are made of nonmetallic material and mounted on ball bearings to reduce noise and eliminate frequent lubrication. Instead of the usual noisy and difficult-to-adjust vertical shaft drive for the coiler, there has been designed a quiet, smooth worm and gear unit which is connected to the gears in the turntable base by a vertical shaft, having flexible universal joints top and bottom.

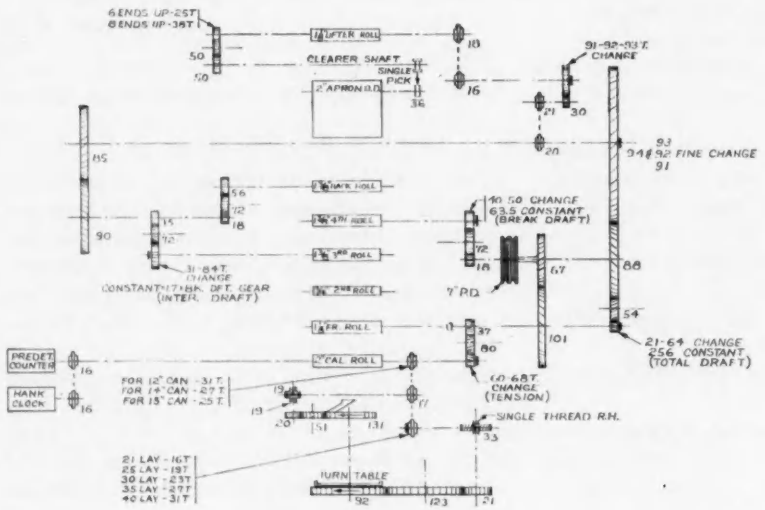


Fig. 3. Schematic diagram of frame gearing.

In this manner the turntable base can be moved to properly fill the cans without any gear readjustment. All bearings are antifriction, grease-lubricated, and require regreasing only once or twice a year.

As mentioned before, the back lines of drafting rolls are driven through a jack shaft. Mounted on the end of the front roll drive shaft, and easily accessible, is the total draft change gear, giving a range of draft from four to twelve. This change gear is connected to the jack shaft through a helical train; and on the end of the jack shaft, equally accessible, is another large gear with 94 teeth. With each head are furnished three extra gears of 91, 92, and 93 teeth, all of the same pitch diameter, which are interchangeable with the 94T. gear. Thus, for fine changes in weight of the sliver, these gears provide about 1% change, or for the usual slivers, a change of approximately half a grain per yard.

In previous years, with multiple process roving, fine changes at the drawing frame were not too important; but today, with one-process roving, and that single in the spinning creel, and sometimes without any roving at all, exceptionally close tolerances must be maintained at the drawing frame.

To return to the jack shaft. This is placed under the roller beam, and at the foot end is another pair of large helical gears connecting with the foot end gear stand (Figure 4). Here is the take-off for the third and back roll drive. The gears on both rolls are large, easily accessible, and the intermediates are mounted on swing arms, ensuring correct meshing with the pinions.

The fourth line of rolls is driven at the head with a similar unit construction. All these slow-speed change gears are 18 P. 20° pressure angle, ⅞ face, with ⅞ diameter bores, identical with those used on all our recent drafting assemblies on roving and spinning, beginning with the Gwaltney frame. It will be appreciated that this standardization of draft change gears simplifies inventory and production requirements. These same change gears are used on the lifting roll drive and for the drive of the automatic clearers.

All the rolls, top and bottom, are mounted on antifriction bearings. Most of the bottom steel roll bearings and all the top roll bearings are Torrington needle, similar in construction to the millions we have had in service for several years. On all lines, next to the gear that drives the roll, the roll stand has a large ball bearing to take radial gear loads and position the rolls laterally (the assembly is shown in Figure 5). This is accomplished because of the jack shaft drive, and is not possible where gears are bunched together at one end, as in a single end drive. On existing drawing frames, every mill has experienced the trouble of worn bearings next to the driven roll gears, caused by the force of the gears. In time, these worn bearings usually produce a crank action in the rolls.

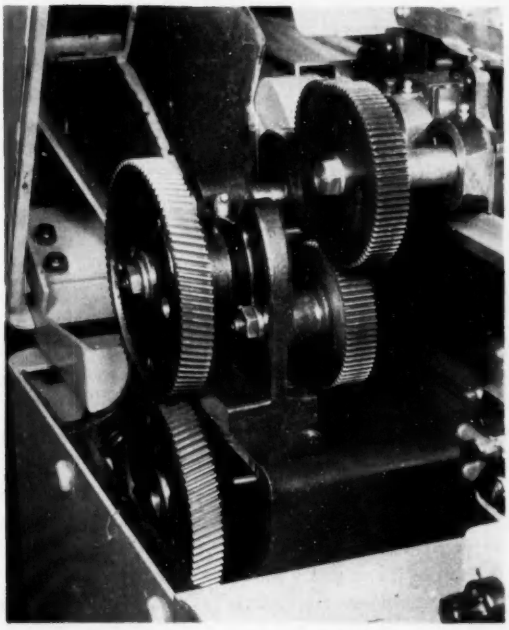


Fig. 4. Gear stand. Shows take-off for third and back roll drive from countershaft.

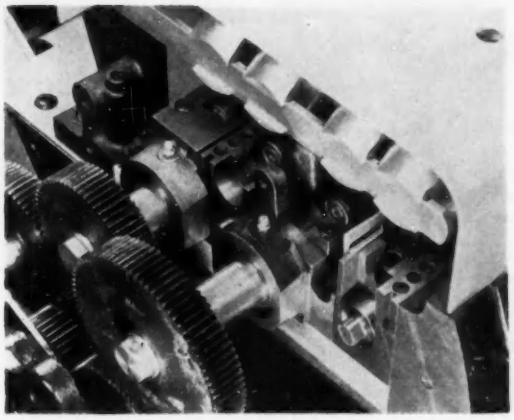


Fig. 5. Steel roll bearings (showing accessibility from top).

and become another hidden source of error in the drafting pattern. The construction described above eliminates this error forever.

Figure 5 also shows the socket head cap screws that hold down the roll stand slides. Fully accessible from the top, they greatly facilitate resetting of the rolls.

Weighting

Several drawing frames have been equipped with overarm spring weighting during the last two or three years. Springs have largely replaced dead weights on all new frame installations. They are more efficient, and because of their light mass, respond to the variations and vibrations of the rolls more quickly than heavy weights. This is particularly important when the roll speeds are running so much faster.

There are two construction features in the top arm which are new, novel, and worth while, and for which Saco-Lowell has applied for patents. All springs are very stable today, and if correctly designed, with the mountings made so that they cannot be incorrectly stressed, will last indefinitely—practically forever. However, most top rolls, particularly on drawing frames, have to be ground or buffed from time to time, resulting in varying diameters. As the load transmitted by a spring is dependent upon its working length, the resulting pressure is varied accordingly. Where springs can be made long enough, the gradient can be designed to take care of minor variations in spring length. However, the space available in an overarm construction is usually less than that available with the old style springs placed under the beam, and the length dimension of the spring becomes more critical. Even with the older type springs, hidden as they were below the beam, it frequently happened that one spring, or unit, was not properly adjusted, thus creating another source of hidden errors in the sliver.

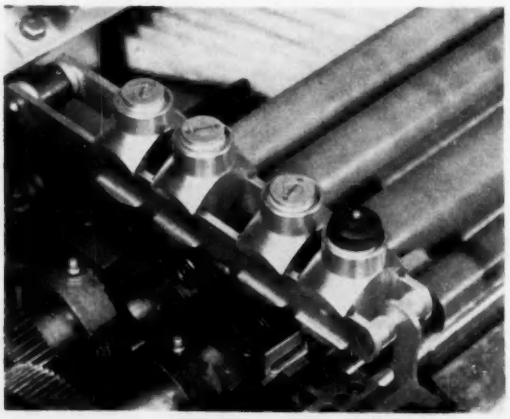


Fig. 6. Top roll spring units. Note plungers for indicating correct pressure.

To overcome these defects, a spring unit has been designed with a small plunger, or pin, in the center of each spring cartridge (see Figure 6). By means of a special spanner wrench ("special" so that the operator cannot toy with it), the plunger is adjusted so that the top of the pin is flush with the top of the cartridge. This makes the spring length the same, irrespective of the diameter of the top roll, and ensures correct pressures at all times. An instantaneous glance will show a protruding or depressed pin if something is wrong. Thus, the troublesome problem of "hidden" errors is overcome.

To facilitate adjustments when changing roll settings, the spring units are simply slid back and forth in their frame to match the bottom roll settings. These top spring unit settings are not critical, the foot of the plunger merely sitting on top of the roller bushing anywhere. No set screws have to be tightened up or unloosened to make the adjustments. The spring units are frictionally held in place by small flat springs when not in contact with the top rolls. When the unit is clamped in place by the eccentric toggle levers, each unit is securely anchored by the full pressure of the top roll spring.

The rolls, gearing, and weighting are only a few of the new features of this altogether new drawing frame. Let us start at the back of the machine, with the creel.

Creel

In the majority of cases this frame is furnished with a creel for eight ends-up at the back. With two-process drawing, 8×8, or 64 doublings, seems to provide the right number of doublings required to level out the average card sliver for quality work.

The creel can be shortened for six ends-up per delivery if desired. The spacing between the arms is varied to suit the size of cans—up to 18×42 in. if necessary. Naturally, this increases the floor space, and eight 18-in. diameter cans extend 13 ft. back of the frame. The creel guides are angled slightly to provide more operator space. The guides are made of smoothly finished cast iron, and coated with baked enamel, without cracks or crevices, so as to provide

a slippery surface for the slivers to slide over. In general, metal has been found better than plastics because it generates less static and has a higher impact strength.

Calender Rolls

The calender rolls, their bearings, and method of mounting, are entirely new and different.

The bottom or back calender roll is mounted on ball bearings and driven at the head end through helical gears, as described in the diagram (Figure 7). The ball bearings for the back calender roll are securely held in the roll stands while the front calendar roll bearings are free to move in or out, with true *rolling*, not *sliding*, friction. To provide the necessary pressure on the front calender, a spring-actuated bell crank lever is mounted in each roll stand. The compression springs are neatly housed in the roll stand, and exert about three times the pressure on the calender rolls because of the mechanical leverage of the bell crank lever. The ball bearings are large, grease-lubricated, for trouble-free performance.

Tube Gears

Ever since Tatham invented the coiler in 1845, the tube gear construction has remained about the same; i.e., a gear, running in a raceway in a plate, with an angled hole to place the sliver in a circle.

Until recently, all these gears have turned in plain bearings with a rather large diameter track, which was quite a problem to keep lubricated. This construction worked fairly well until larger cans and higher speeds were required. These meant a surface speed between the tube gear race and the tube gear plate of approximately 300 ft./min. instead of the former 100 ft./min. Even with adequate lubrication, frequently applied, the tube gears ran hot at high speeds; and oiling the track is a messy affair at the best, with occasional oil contamination of the sliver, no matter how carefully the oiling is done. The answer was obviously antifriction bearings. But how? If mounted at the top, there is danger of eccentric loading, which is very detrimental to the life of ball bearings. If mounted in the ring, ball speeds are quite high, because of the large diameters, and concentricity on the large diameters is difficult to maintain.

It was decided to mount the gear on ball bearing trunions. This keeps the ball bearings small and provides completely enclosed grease lubrication. The trunions have tires of graphite-impregnated phenolic plastics. Test gears and trunions have been running for over a year in the Saco-Lowell laboratory under excessive speeds and loads, and show only a polishing of the trunion tires, and no wear of the tube gear. The tube gear assembly is shown in Figure 8.

Instead of the usual bevel gear drive for the tube gears, which was noisy and wore rapidly, we have designed an entirely new drive. Placed adjacent to each pair of tube gears is a small helical gear box. These gears are driven by a longitudinal shaft from the head end, with a nylon coupling between the shaft and the gear box. At the bottom of each gear box is a small steel pinion that meshes with a nylon intermediate gear positioned between each of the tube gears. The intermediate gear is also mounted on ball bearings, and is grease-lubricated. This gives a completely antifriction bearing tube gear and drive assembly, with no oil to contaminate the sliver, and not even any exposed grease, because the nylon intermediate gear eliminates any lubrication of the gear teeth.

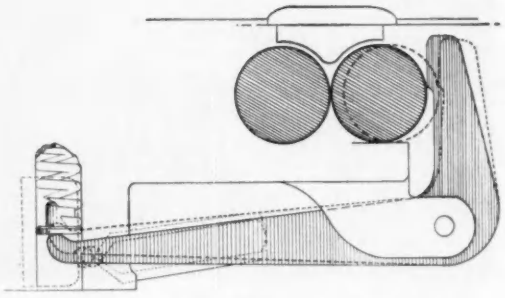


Fig. 7. Spring-actuated calender roll loading.

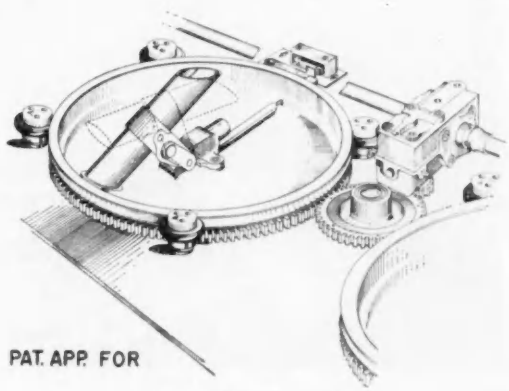


Fig. 8. Coiler assembly.

Coiler Base Plate

Like the rest of the frame, the housing of the base plate is formed from plate steel, making it practically indestructible. Likewise, the turntables on which the cans rest are turned from $\frac{5}{16}$-in. boiler plate. Instead of a raised rim, these turntables have a depressed flange which centers the can from inside the bottom, rather than from the outside. This has two advantages. It eliminates the raised flange on the turntable, which is frequently cracked and broken, and makes it possible for the operator to remove the full can by simply sliding it off the turntable without lifting it over a flange, and this is very important when the gross weight is 30 or 40 lbs. or more.

The turntables and their intermediate gears revolve on the only plain bearings on the frame. However, these are wick-lubricated from a well, filled with oil, and should run at least a year between reoilings.

The turntables are driven by cut gears and receive their motion from the vertical shaft mounted on the head end. The turntable base may be adjusted lengthwise of the frame in order to properly fill the can without any gear readjustment. Lengthwise adjustment allows a minimum of distance from the front of the frame to the drafting rolls. This is especially desirable with large diameter cans.

Clearers

In all fiber handling processes, some fibers separate themselves from the mass and cling to other parts of the machine or fly off into space. Combed cotton is particularly troublesome in this respect, so it was natural that the cleaning of drafting rolls on combers had to be solved, especially since the comber being used handles heavier laps and operates at higher speeds and longer drafts of the drafting rolls than most combers.

There have been, and still are, many different types of clearers; some good, some fair, but none without some defects. The old Ermen-type of clearer, when new and properly adjusted, was very effective, and most fine-goods mills demanded them. However, the cloths or aprons had to be kept tight in order to drive them, and the adjustments were critical.

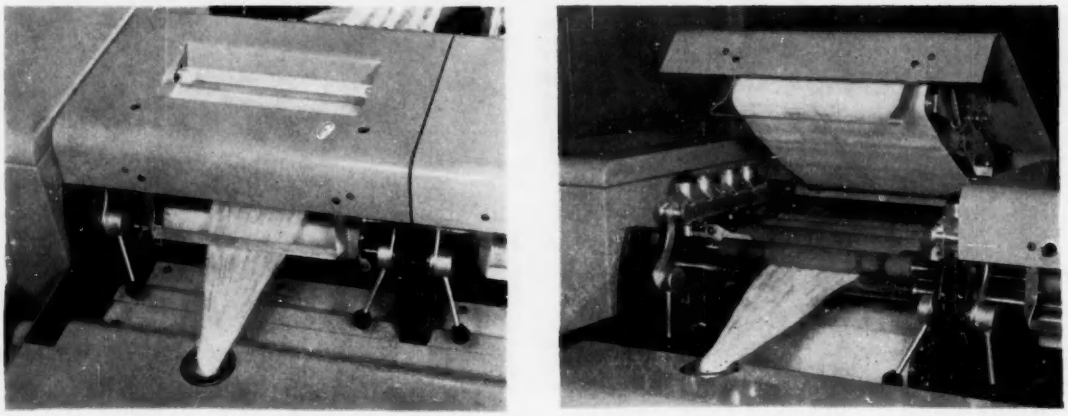
The automatic clearers used by Saco-Lowell have been designed to overcome the faults of the Ermen clearer and retain its virtues (Figure 9). A drive has been found that will drive the cloth apron, no matter how slack. (Patent applied for.)

The angle of the comb has been made adjustable, and the teeth made finer, to ensure adequate cleaning and minimum wear of the nap. The old hard action drive was replaced by a new smooth one, and oil lubrication was eliminated by the use of nylon or other dry bearings.

A unit of similar construction has been designed for the bottom steel rolls. Thus, every line of rolls, top and bottom, is effectively wiped by a positively driven cloth apron, and the waste carried away to a point where it is easily collected. Similar clearers have been standard for over two years, and have proved very satisfactory.

Covers

Besides the clearer covers, all the other covers are constructed with smooth, lint-shedding contours.



a b

Fig. 9. Automatic clearers.

Furthermore, many of these are lined with sound-dampening material. The covers that enclose the gears have electric interlocking switches; and unless the covers are closed, the frame cannot be started. The electric controls, including a disconnect switch, are all enclosed in a cabinet built into the front of the head end; protected, but accessible.

Stop Motions

Years ago, there was some opposition to electric stop motions, largely because sources of electric energy had to be generated right at the frame; then the electric stop motion had to operate a mechanical contrivance to ship a belt from the tight to the loose pulley. Naturally, there were many failures, and there was considerable maintenance.

Today, with all-electric drives, the stop motion can be operated electrically all the way, and there is no question but that it is cleaner, surer, and faster than any mechanical stop motion. With these high speeds, fast, positive stops become paramount, and to secure maximum efficiency electric stop motions have been incorporated in five positions, with four colored indicator lights.

One of these is at the back where the slivers enter. Individual plastic notched guides lead the slivers into the back sliver rolls (Figure 10). Whenever an end breaks or runs out, a top roll drops and makes contact with the bottom roll, completing the electric low-voltage circuit. By means of a small, sensitive relay, the low-voltage circuit actuates a circuit breaker in the motor control circuit and cuts out the main driving motor. To be certain that the machine and motor do not coast to a long stop, the motor is equipped with a Stearns magnetic brake which ensures quick, positive stops, with the minimum of sliver run.

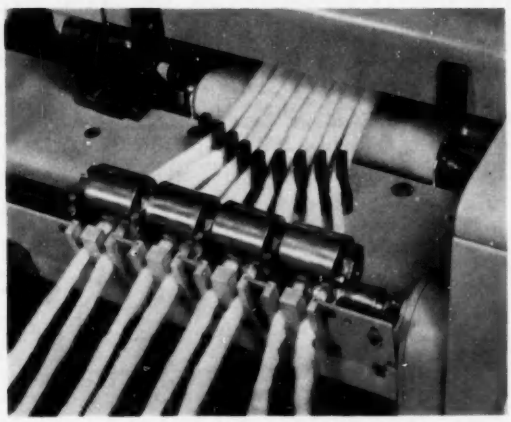


Fig. 10. Sliver entering drawing frame showing sliver guides and lifting rolls.

The second point protected by stop motions is the front rolls, top and bottom. As described earlier, the top roll spring units have small pins or plungers that are lifted by the top roll bushings. In case of a lap-up on either top or bottom roll, this plunger protrudes beyond the top of the spring unit. On top of the front roll spring units are secured small rubber caps with brass inserts. A thin, nonconducting washer spaces the brass inserts from the spring pin. If a lap-up occurs, the small pin in the spring unit projects upward the thickness of the washer (about $\frac{1}{64}$ in.) and makes contact with the brass insert, which in turn is connected with stop motion and relay. This makes a very effective and foolproof stop motion, and is indicated by a yellow light.

For the calender rolls, the long arm of the bell crank lever also carries a small adjustable pointed cam that actuates the stop motion switch. If a lap-up occurs, the calender roll bearing moves away, forcing the lever up and the pointed cam away from the contact roller of the microswitch, as shown by the dotted lines, stopping the frame. If the sliver runs out, the calender roll and its bearings move in, and again the pointed cam slips off the control roller of the microswitch, stopping the frame. Because of the mechanical leverage of the bell crank and the sensitivity of the microswitch, only a few thousandths movement of the calender rolls is necessary to stop the frame. There are no open contacts; no points to foul or become corroded; no sliding bearings to stick or bind. All in all, it is an extremely simple, rugged, trouble-free assembly, and yet extremely sensitive and accurate. (See Figure 7.)

The tube gear has its own built-in stop motion (patent applied for). Sliver plugging in the tube is well known. Sometimes there are yards and yards of stock wedged between the tube gear and the calendar rolls; and the calender rolls, even though equipped with stop motions, go on delivering sliver. The newest tube gear has the tube pivoted, as shown in Figure 8. As soon as any appreciable sliver accumulates, the tube tips down at the top, as indicated by the dotted lines on the slide. This releases a plunger which actuates a microswitch, stopping the frame, and indicated by a blue light. Thus, another fault of the drawing frame tender has been eliminated.

To be certain that each can will contain the same amount of sliver, we have directly connected to the

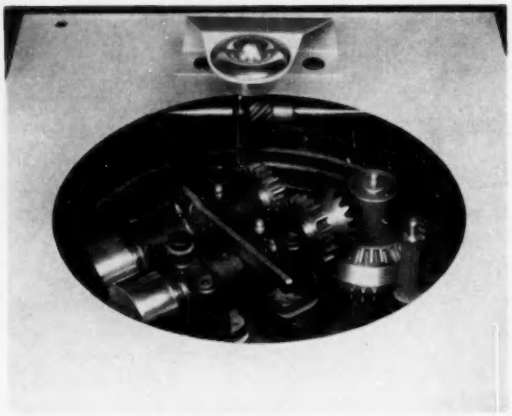


Fig. 11. Positube coiler assembly.

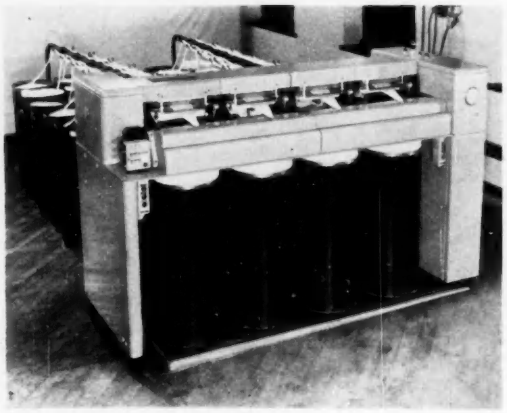


Fig. 12. The Saco-Lowell Versa-Matic drawing frame.

back calender roll an electric yardage counter (shown in Figure 2). The dial is set to the number of yards desired in the full can, commensurate with the diameter and height of the can and the character of the sliver. When the indicated number of yards has been run, the counter makes an electric contact, stopping the frame, and indicated by the red light. This counter is far more accurate than the old mechanical knock-off, and all cans creeled together will run out at the same time, thus saving tailings and waste. Again, this is more important with large cans, as they are so heavy they cannot be easily tipped upside down to recover tailings, and 42 in. is beyond arm reach.

From the preceding description, it is evident that the specifications for this new drawing frame for processing cotton have been fulfilled. It is also very adaptable for processing rayon, synthetics, wool, and other long staple fibers. The 4-over-5 construction permits running staples up to 2 in. long. For longer fibers the back roll is removed and the frame becomes a 3-over-4. Usually the longer fibers have coarser deniers which are easier to straighten and do not require as much break draft. Frequently they have already been straightened by gilling or pin drafting. However, the drafting operation may increase the static charges and the slivers become difficult to get through the conventional tube gear.

In this case the Positube Coiler assembly (Figure 11) would be better than the conventional calender rolls and tube gear. This mechanism has small gear-driven calender rolls mounted in the revolving plate gear, and positively delivers the sliver into the can.

Another variation of the tube gear is the Twinstrand assembly. Here two tube gears per delivery permit splitting of the web into two slivers, coiled separately within the same can. This eliminates any tendency for one sliver to amalgamate with another, and ensures the removal of each sliver from the can without affecting the other. This Twinstrand construction is very helpful in reducing the floor space behind the roving, and it is being made standard for the can-spin installations where the yarn is spun directly from sliver.

Because of its versatility, the new drawing frame has been named Versa-Matic (see Figure 12). It will undoubtedly become a new tool for textile mill processing; and, like the one-process picker, long draft roving, and the Gwaltney spinning frame, will prove epochal in improving the product and reducing cost.

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